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Johan Jacob Tesch.

1877—1954.

DR. Johan Jacob Tesch passed away on 7. August 1954 in The Hague, where he had lived for many years.

His scientific life was wholly devoted to the sea. In 1908 he was appointed as a biologist to the Dutch Institute for Fishery Investigations at Den Helder. There he carried out valuable work on the quantitative distribution of fish eggs and larvae in the southern North Sea, on the biology and systematics of Copepods, Amphipods, and Decapods, and on the biology of the sole. He developed a method for assessing the age of soles from the rings on the vertebrae. In 1915 his liking for

systematic work led him to accept a place in the Museum of Natural History in Leyden, but in 1918 he returned to the Fisheries Service, in which he was charged with the North Sea fisheries investigations. This post he held until he retired. He had a difficult task, being the only biologist engaged on this task, and he worked with a minimum of equipment.

During this period he was engaged on two important studies and the results of his work show how clearly he was able to appreciate a situation. Between the two world wars an intensive fishery for small fish, especially immature flatfish, took place on the nursery grounds along the Dutch coast. These fish were largely used for poultry food. T e s c h saw that this procedure would have a fatal influence on the fish stocks and his first report on this subject concluded with the words (translated into English) "the use for duck food or the manufacture of fish meal of young fish that could attain marketable value one year later and so have a considerable latent monetary value is a regrettable excrescence on our fishery." It is due to T e s c h' s efforts that this "regrettable excrescence" has been completely eradicated.

T e s c h carried out extensive investigations on the young herring that at times occur in huge quantities in the Dutch estuaries, where they are caught for industrial purposes. In the period between 1921 and 1925 the drift-net catches fell to a low level and it was thought that this might have been caused by the capture of too many young herring. T e s c h worked out the populations to which these young herring belonged and came to the conclusion that on their existing scale, the catches of immature herring from the various populations could not exert a significant influence on the herring stocks as a whole.

T e s c h' s larger works comprised "Die niederländische Seefischerei" (*Handbuch der Seefischerei Nordeuropas*) (with J. d e V e e n) and "Het leven der Zee".

During the last war, when he was cut off from the sea, owing to the closure of the coast by the Germans, T e s c h returned to his old love, systematics, and it was especially the Pteropods collected by various expeditions that occupied him. He continued this work after he was obliged to retire in 1942, on account of age, and he did not lay down his able pen and drawing pencil until shortly before his death.

T e s c h was the Netherlands delegate to the International Council from 1926 until the war broke out. The older members

of the Council will recall his cultured mind and his great knowledge of literature.

He was also a very kind man, who coupled high erudition with a humane and civilized outlook. He spoke French, English, and German fluently. I felt it an honour to be counted as one of his many friends, who will all miss him greatly.

B. Havinga.

Editorial Notice.

The Second International Seaweed Symposium has been arranged to take place between 13. and 23. July 1955. The meetings will be held at the Norges Tekniske Høgskole, Trondheim, and will be followed by tours to Molde, and thence to Bergen or Oslo.

The main subjects discussed at the meetings will be the chemistry of seaweeds, their industrial exploitation, use in nutrition, and algological studies of species used industrially.

An Organizing Committee has been set up under the chairmanship of Professor T. B r a a r u d, Blindern, Oslo, from whom further information may be obtained.

Some Considerations Regarding the Nutrition of Marine Fish Larvae.

By

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I. Introduction.

It was reasoned by Hjort (1914) that the size of a year-class of marine fishes is determined during the very early developmental stages. Although subsequent studies have tended to support Hjort's contention, the actual causes of success or failure of a year-class have not been determined.

One of the most important factors for survival is food. There have been only a few detailed studies of the food habits of marine fish larvae. Lebour (1916—18, 1919—22 b, and 1919—22 c) examined the gut contents of many fish larvae representing a large number of marine species. Lebour (1919—22 c: 262) stated:— "One finds that certain copepods and other Entomostraca constitute by far the larger part of the food of nearly all the very young fish, and that usually each species of fish selects its own favourite food to which it keeps, indiscriminate feeding seldom or never taking place, and one can usually assign to each fish its own particular food. The diet of the fish, however, depends to some extent on the size of the mouth and gullet and in a few fish a unicellular diet is the rule up to a considerable size.

Few fish are vegetarians, and it is unusual for any but the youngest fish to eat diatoms ... Very young herring and sprat and a few others often contain green remains which probably belong to some algae, and occasionally diatoms can be recognized in this, but even before the yolk sac is absorbed the gut may contain larval molluscs and small crustaceans, as in the young herring."

Lebour's findings have lent much weight to the current view that early larvae of marine fishes depend almost exclusively upon food particles of relatively large size.

Fish larvae kept in laboratory tanks display characteristic patterns

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of feeding behaviour. Lebour (1919—22 a) described such patterns for several species. Other investigators engaged in the rearing of larval fishes have also noted that among the very young, feeding is apparently a deliberate process. I have kept larvae of a number of species in laboratory containers and their behaviour certainly suggested that they were dependent upon food particles 40 to 50 μ in diameter, or larger.

II. Food Habit Studies.

Studies of the food habits of fish larvae have been conducted by both observational and experimental methods, (cf. Lebour, 1919—22 a and 1919—22 b). There are some serious limitations in each of these methods.

Crude observations of the gut contents of larvae collected from nature show what microscopic forms have been recently ingested. They do not show, however, the extent to which the ingested particles nourish the larvae. In the larval guts many organisms can be found which show no erosion of the integument or other indication that they were being digested at the time of collection. To conclude that easily identifiable objects in the gut represent *the* food of that particular larva always calls for a measure of faith.

It is extremely difficult to establish an approximation to a natural pelagic habitat that will be satisfactory for controlled experiments. There is always a question as to what distortion of behaviour may be induced by the unnatural environment. With few exceptions, it has in the past been impossible to rear the larvae of marine fishes through the period during which they first begin to feed, and comparative studies bearing upon that period have not yet been made.

Both observational and experimental methods, but particularly the experimental, are limited by the fact that the choice of food will necessarily be confined to that which is available to the larvae.

III. Pütter's Theory.

Among the concepts of nutrition of aquatic animals there has perhaps been none so controversial as that known as "Pütter's Theory". Pütter investigated experimentally the nutrition of a number of aquatic animals from several systematic groups and came to the conclusion that their survival depended heavily upon direct utilization of the dissolved organic constituents of the water. Pütter concisely expressed his beliefs at the conclusion of his monograph (1909 a: 147):— "Die Ernährung eines grossen Teiles der Formen aller Stämme vollzieht sich nicht in der Weise, wie man es bisher, in grosser Analogie mit den Säugetieren und Vögeln annahm; d. h. dass geformte Nahrung aufgenommen, durch die Verdauung gelöst und gespalten und in diesem Zustande resorbiert wird, sondern eine grosse Anzahl von Tieren, speziell die absolut kleinen Formen aller Stämme nehmen, soweit sie im Wasser leben, ihre Nahrung direkt in gelöster Form aus dem Wasser auf."

Pütter published a number of other papers in support of his theory (cf. references in Krogh (1931) or Bond (1933)).

Contemporaneously with, and subsequent to, Pütter's research, a number of investigators contributed to this subject. The findings of these other investigators were largely negative. When the matter was reviewed by Krogh (1931) it was concluded that animal forms higher than protozoa and sponges were without mechanisms for directly utilizing dissolved organic nutrients, at least under any approximation to natural conditions, where such solutes are present in only very dilute concentrations.

IV. Some Factors to be Considered.

Pütter's and subsequent research on fishes.

Pütter (1909 a and 1909 b) described his investigations of the nutrition of five forms of marine fishes, *Hippocampus, Balistes, Scorpaena, Gobius,* and *Heliastes*. Since that time many animals have been used as subjects for testing Pütter's Theory and some of the tests have been conducted with extreme refinement (cf. Bond, 1933). Is is over 40 years, however, since *marine* fishes were subjected to tests of this theory (Moore *et al.*, 1912).

Moore *et al.* experimented with several marine animals to determine whether or not they could utilize dissolved organic matter present in the water. Only one of their animals was a fish, *Blennius*. Their work was carefully executed but limited in scope (a single specimen weighing about 10 g. in 2800 ml. of Chamberland filtered sea water for a period of 24 hours), and although it did demonstrate that the fish did not gain from dissolved organic matter, there remains the possibility that it might have done so under somewhat different circumstances.

Incidence of particulate feeding.

Summarizing his section devoted to supply and demand of food among aquatic animals, Krogh (1931: 419) stated:— "... both among the fishes and among the invertebrates we have to do with carnivorous animals which take food only occasionally, and the intestine of which is therefore empty when digestion of a prey is finished. In many fishes the intestine is empty in the morning, because food is taken only during the day ... For a number of the fish which, according to Pütter, would take only quantitatively insignificant amounts of particulate food, it can now be stated on the authority of Blegvad and Marie Lebour, that they can and do obtain a sufficiency of such food, but the fact remains that in a number of cases the information with regard to the quantities of food which are eaten is very incomplete."

Lebour (1919—22 c: 269) stated:— "The large number of empty guts in some of the young fish, especially the clupeoids, is striking. Green food remains are often found in the very young sprat, but the herring and pilchard are more often empty." and (1919—22 d: 458):— "Whilst investigating the food of young fishes in general (Lebour, 1918—1919

—1920) some thousands of young clupeoids were examined with the result that by far the larger proportion of post-larvae were found to be empty . . ."

Contrary to K r o g h' s statement (*op. cit.*), none of L e b o u r' s findings proves that fish larvae can and do obtain a sufficiency of such food particles as she described.

An exhaustive study of the biology of the Pacific sardine, *Sardinops caerulea,* has been undertaken since 1949 by the California Cooperative Oceanic Fisheries Investigations. In the course of this study, a vast amount of physical and biological data has been collected. With the specimens and data available, David K. A r t h u r of Scripps Institution of Oceanography is investigating the food relationships of the larvae of the sardine and some other species. According to A r t h u r' s findings (orally communicated progress reports), sardine larvae less than 10 mm. in length feed primarily on the eggs and nauplii of copepods; they feed largely during daylight hours; the incidence of their feeding is very low.

The "low incidence of feeding" (i.e., among collections of larvae, one generally finds food organisms in the guts of only a very small percentage of the specimens) is apparent to, and remarked upon by, anyone who has spent much time in the study of marine fish larvae.

A number of theories could be reasonably advanced for this low incidence of feeding, but the fact remains that until it is positively explained, there is no justification for assuming that the stocks of larger, animate food particles are adequate to sustain larval populations.

Digestive rate.

K r o g h (*op. cit.*) stated:— "In many transparent forms like larval fish the digestion is extremely rapid and the gut appears empty most of the time." The authority for this statement is apparently L e b o u r (1919—22 d: 458) who said:— "A probable reason for this apparent absence of food in the transparent stages is that the food must be very quickly digested on account of its being so conspicuous; thus it is probably taken only at long intervals and rapidly got rid of."

It is evident that L e b o u r was theorizing about the rate of digestion and did not present her statement as an established fact. There seems to be no evidence that digestion of the types of food described by L e b o ur is extremely rapid, and the fact that she was able to identify rather precisely so many of these food organisms would suggest the contrary (even if we grant that identification was made from those body parts of material such as chitin which could not reasonably be expected to be digested).

Among a large number of larval fishes held in the laboratory I have seen no indication that digestion proceeded at a very rapid rate, nor has it appeared to be very complete (i.e., digestion of such things as nauplii and veligers).

Nutrition of embryos.

Larval stages are still essentially embryonic in function and the successful development of embryos is predicated upon a sustained and

immediately available supply of food. When the larval yolk is exhausted there is a period of time during which the larvae of most species of marine fishes are without food-storage tissues or organs which can sustain them for long. In many forms, reserves in such organs as the liver appear to be exhausted in a matter of hours.

W u n d e r (1936: 228—233), in discussing alimentary tracts of fishes, characterizes those of predacious habit as having a capacious stomach which enables them to pursue a "feast and famine" type of existence. On the other hand, fishes such as the cyprinids have no stomach and take their food in small amounts, frequently and regularly. Grossly, the position of the stomach in the very young larvae of many species of marine fishes is indicated only by the constriction of the pyloric valve. There can be no storage in the stomach, and whatever function the stomach may have in their digestive processes would have to be extremely rapid, because a food particle such as a nauplius passes from the mouth to below the pyloric valve in a matter of seconds. (Ingested nauplii of *Artemia* are still alive when they pass the pyloric valve of, for example, young larvae of the herring, *Clupea pallasii*.)

There is no evidence that marine fish larvae reduce energy requirements by becoming passive during the lengthy periods of time between particulate feedings. The fact that many larvae tend to rise to upper layers at night (when directive feeding is presumably of lowest incidence) suggests that activity is not suspended.

Organic matter in the sea.

One of the main arguments against P ü t t e r' s Theory was the prevalent belief that organic solutes are extremely dilute in sea water. Recognizing certain deficiencies in techniques used in the earlier work, S v e r d r u p *et al.* (1942: 249), in their discussion of P ü t t e r' s Theory, stated:— "Although the problem has attracted much discussion and speculation, there are very few trustworthy data concerning the amounts of carbon present in particulate or dissolved matter in the sea."

In examining the literature, one is almost forced to conclude that some of the participants in the controversy over P ü t t e r' s Theory were inclined, in discussing quantities and distribution of organic matter, to use data which favoured their particular beliefs. Not only the amounts of organic matter, but also the state to which the organic matter is subdivided, have apparently been misunderstood. The organic matter that has been referred to as "dissolved" by various authors has obviously included material of substantially different size categories, reflecting the manner in which water samples were treated and analysed. Techniques in sampling, filtering, centrifuging, and analysis of the organic matter have not yet been standardized. It is apparent that some early investigators testing P ü t t e r' s Theory failed to appreciate physical and biological processes (e.g., adsorption and microbial activity) which keep the organic system in constant flux, causing particular distortions of the natural picture when water samples are removed from the sea and taken into

the laboratory. The actual composition of the inanimate organic constituents of sea water appears to have eluded difinition. And over all this, the natural variation in distribution and quality of organic matter, both living and dead, imposes a factor which has tremendously magnified the difficulties.

In spite of these many difficulties, one obtains the impression from the literature that there is a much greater amount of "dissolved" organic matter in the sea than exists in the particulate state. ZoBell (1946: 19) gives the ratios that have been found by different investigators as ranging from 1 : 7 to 1 : 4000 (particulate : dissolved).

As pointed out earlier, attention has for the most part been focused upon organisms of 40 to 50 μ in diameter or larger in the study of feeding habits of marine fish larvae. The ratios given above show that such organisms would probably constitute only an exceedingly small fraction of the organic matter present in a given body of water. Since feeding upon such organisms has appeared to take place so infrequently and irregularly, let us consider some of the other possibilities.

It is impossible for larvae to feed upon organisms larger than they can take into their mouths and swallow. Since the organisms to be found in the guts of larvae less than 10 mm. in length usually approach these limits, it seems that the material heretofore considered to constitute their diet might possibly represent only a small fraction of it, from the uppermost portion of the conceivable size range.

If such organisms as dinoflagellates and diatoms were taken to any appreciable extent, they would undoubtedly have been noted in the course of routine procedures of gut analysis. This is not the case, however, since such organisms are only rarely found in the larvae.

It is conceivable that nanoplankters such as bacteria and certain flagellates would be overlooked in routine gut analyses because of their small size and lack of colour. No extensive work has been done to determine the possible significance of such organisms in the diet of larval fishes.

Further down the size scale is the "dissolved" organic matter. Recent investigators using methods presumably more highly refined than those used by earlier workers have made some interesting observations.

Collier *et al.* (1950) described some organic matter that they have found as follows:— "The characteristics of the substance as it occurs in the natural sea water supply of this laboratory are as follows:— It passes bacteriological filters and is not thrown down by the ordinary laboratory centrifuge. The concentration in different samples ranges from 2 to 25 mg./l. and is extremely variable."

Fox *et al.* (1952) introduced the term "leptopel" and defined it as ranging from:— "... finely colloidal micelles to minute visible particles and including intimately associated micro-organisms such as bacterial cells, [which] will vary in quantity and in chemical constitution with reference to latitude, depth, season, and proximity to land."

Among a number of samples they found quantities of organic

leptopel to vary from 0·25 to as high as 35·3 mg./l. Some of the material considered by P ü t t e r (1909 b) appears to have consisted of this leptopel (rather than true solutes).

Although much remains to be determined regarding the suitability of dissolved organic matter as an energy source for marine organisms, certain fractions have been shown to be very important as growth factors (cf. W i l s o n, 1951). In such capacity, they profoundly affect distribution and survival of at least some higher forms of animals.

Utilization mechanisms.

The most serious objection to P ü t t e r's Theory was based on the failure to find physiological mechanisms whereby dissolved nutrients could be concentrated and absorbed from dilute solution in natural waters. Regarding mechanisms, K r o g h (1931) stated that at least one of two things must take place, (1) diffusion or (2) active transport. P ü t t e r stressed the extent of surface area as the factor governing the amount of utilization of dissolved matter, and the two mechanisms considered by K r o g h obviously refer to acquisition through the integument.

Direct simple diffusion through the integument under natural conditions would, as K r o g h stated, be impossible because it would be directed against the concentration gradient. The permeability charcteristics of most integumentary processes cannot be expected to favour such diffusion, and mechanisms for the concentration and active transport of organic molecules through the integument have not been observed.

Other possible methods by which dissolved food materials might conceivably be gathered have not been sufficiently considered. A natural biological filter was described by M a c G i n i t i e (1945). The echiuroid worm, *Urechis caupo*, lives in a U-shaped burrow in the mud and pumps water through the burrow by peristalsis. The animal secretes a conical net of mucus which is open at the base, with the basal periphery attached to the burrow, and the apex of the cone attached around the anterior end of the worm. In such an arrangement, water pumped through the burrow must pass through the mucous net which strains out the food. After a period of pumping, the net with the food particles it has retained is eaten, and the process is repeated. M a c G i n i t i e found that the interstices of the net retained particles having a diameter of approximately 40 Å. Recognizing the adsorption that would take place on such a net and the progressive clogging of its interstices, we have here a mechanism that would enable the animal to concentrate and deliver to digestive surfaces molecularly divided materials of even smaller dimensions than the diameters of the net openings would imply.

While the mechanism found by M a c G i n i t i e is probably nothing like those sought by the earlier investigators, it is nevertheless a mechanism for utilizing the "dissolved" organic matter of sea water.

C o l l i e r *et al.* (*op. cit.*) found that the naturally occurring, filterable organic matter observed by them could induce oysters to pump when it was present in the water above certain threshold values (the threshold

varied with temperature). These authors also found that an oyster would remove from 5 to 15 % of the substance from the water passed through its body.

Although Collier *et al.* did not isolate the mechanism of collection, they demonstrated that one is present. Of equal importance is their demonstration of the presence of a mechanism with which the oyster detects and measures the amount of the organic substance in the water (the greater the carbohydrate concentration, the more water the oyster pumped).

Fox *et al.* (1953) demonstrated the ability of two representative filter feeders (one setous, the other ciliary and mucous) to collect by adsorption colloidally dispersed particles as small as vertebrate oxyhaemoglobin, i.e., 40 to 50 Å. The animals used in this demonstration were a mysid crustacean (not specifically identified) and the sea mussel, *Mytilus californianus*.

The feeding mechanisms of *Amphioxus* and tunicates were reviewed by Yonge (1928: 45—46). In these forms it has been seen that when water is passed over mucous tracts by ciliary action, food particles are caught by the mucus and carried into the digestive system. It would appear that the mucous tracts in these forms could pick up not only particulate matter but material in the colloidal and perhaps molecular size ranges as well.

Let us turn now to the condition in the larvae of some marine fishes.

The general understanding of osmoregulation in bony fishes began to emerge about 1930 (cf. Smith, 1932). It is now understood that "marine teleosts swallow relatively large quantities of sea water which subsequently undergoes absorption" (Smith, 1930: 501). The actual rate at which water must be swallowed depends in some degree upon the rate at which water is lost and salts gained through body surfaces, and hence upon the extent of those surfaces. It is interesting to remember in this connexion the fact that Pütter related the amount of dissolved nutrients taken up from the water to the extent of body surfaces, particularly gill areas (hence his stress upon benefits to organisms of small size). On several occasions bony fishes have been subjected to tests of Pütter's Theory, but aside from Pütter's original work, and the one individual fish considered by Moore *et al.* (1912), they have all been freshwater forms. Because of the reversal of the osmotic gradient (as compared with marine fishes), these species must avoid swallowing water. Hence, results of such tests on freshwater fishes cannot apply to marine forms. Discovery by an earlier investigator that freshwater fishes do not swallow water appears to have strongly influenced Pütter (1909 b: 210) in his conclusion that the alimentary tract was not the passage through which dissolved nutrients were being taken, even among marine fishes.

In marine teleosts we are dealing with forms in which rather large quantities of the surrounding medium are regularly taken into the alimentary canal and passed through the digestive surfaces. It is improbable that this water could contain enough dispersed organic

matter to be significant in general nutrition. However, if there were some oral mechanism which could collect dispersed organic matter, then whatever water was swallowed might become nutritionally important.

In the course of my studies I have had occasion to examine histological sections of various body parts of the larvae of a few species. The isospondylid larvae examined are the anchovy, *Engraulis mordax*, the herring, *Clupea pallasii*, and the night smelt, *Spirinchus starksi*. Although larvae of the anchovy are only about half the size at hatching of those of the other two species (i.e., *ca.* 3 to 4 mm. and *ca.* 7 to 8 mm. total length, respectively), all three are morphologically similar and during early stages of development the histological conditions of the three compare favourably. Since I have studied the smelt more than either of the other two species, it will be used for reference in the following discussion.

Mucous cells which line the esophageal tract extend forward over the roof and floor of the buccal cavity. When the mouth is distended its floor bulges posteriorly, forming a lateral pouch on either side, at the back of the gill openings. Upon closing, the floor and roof of the mouth are brought tightly together. Although no cilia were found in the mouths of several species examined, musculature across the roof and floor keeps the mucus moving posteriorly in regular, peristaltic waves. It would appear that by adsorption and simple adhesion, these mucous tracts could easily collect the "dissolved" organic matter from water taken into the mouth.

The capacity of the mouth of this larva is about 0·04 μl. Under *laboratory* conditions, in water of 14° to 15°C., and with 95 % of oxygen saturation, the *minimal* rate at which this animal refills its mouth in respiring is about 20 times per minute. At this rate, it would pass across these mucous surfaces about 1·15 ml. of water in the course of 24 hours or 11·5 ml. in a period of 10 days.

The nature of the "dissolved" organic matter that the larva might glean by this mechanism remains an open question. Even with regard to quantity we have no figures based on samples from waters which are known to be supporting populations of such larvae. Arbitrarily, let us take the figures of Krogh (1931: 439):— "Dissolved organic substances are present in fairly large quantities, 10 mg. per litre or more, with a combustion value of 40 cal. per litre or more in most fresh waters. The quantities in sea water appear to be of the same order of magnitude."

In such a solution, the mucous surfaces discussed above would be exposed to not less than 0·11 mg. of "dissolved" organic substances during a period of 10 days. This is an admittedly small figure, but such a quantity might be important in the economy of this larva, whose *wet* weight is calculated to be no more than 0·9 mg.

The condition described in *Spirinchus starksi* is similar to that found in *Amphioxus* and the tunicates discussed by Yonge (*op. cit.*). The musculature effecting respiration and peristalsis in fish larvae appears to be a mechanism similar for all practical purposes to the cilia of the

tunicates in bringing food material into contact with mucous collecting surfaces.

The condition in *Spirinchus starksi* (also in *Clupea pallasii* and *Engraulis mordax*) contrasts sharply with that in such forms as the atherinids. In the young larvae of *Atherinopsis californiensis* less than 10 mm. long, the mucosa is confined to the constricted portion of the esophagus and needle-like teeth are found on the tongue and roof of the mouth. Atherinids can be reared in the laboratory with relative ease, and prosper on a diet of particulate matter such as nauplii — a diet that appears to leave much to be desired in so far as food for such forms as *Spirinchus* is concerned.

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I wish to thank Drs. Joel W. Hedgpeth and Denis L. Fox for valuable comments on the manuscript.

Summary.

It is the general opinion that early larval stages of marine fishes feed almost exclusively upon invertebrates whose sizes range upwards from 40 to 50 μ in diameter. About 45 years ago August Pütter concluded that aquatic organisms depended heavily upon organic nutrients in solution in the water. In testing Pütter's Theory other workers have, for the most part, concluded that dissolved organic constituents of natural waters could be of little significance in general nutrition of higher animal forms. Among the subjects of Pütter's experiments were five species of marine teleosts. Since his original work, only one individual marine fish has been subjected to a test of Pütter's Theory, and this work was done over 40 years ago.

Among marine fish larvae the incidence of feeding (upon the organisms which have been believed to constitute their diets) is extremely low. Since so many larvae collected from nature have guts in which there is no trace of food (as seen in ordinary microscopy), it has been assumed by some that digestion is very rapid. There is no direct evidence for this.

Larval stages are essentially embryonic and it seems illogical to assume that their survival could depend on the "feast and famine" type of existence that a low incidence of feeding would imply. Several aspects of the matter of the very finely divided and dissolved organic substances in the sea have not been brought into sharp focus. Recent studies by other investigators indicate that there may be sufficient quantities of the "dissolved" organic matter (leptopel) to constitute an important factor in nutrition of some aquatic animals. The early larval stages of some marine fishes have an extensive layer of mucous cells over the surfaces of the back of the mouth. Rates at which water is pumped through the mouth during respiration indicate that the mucosa might serve as a mechanism for collecting important quantities of dispersed organic matter of a nature that would have been overlooked

in the course of the routine gut analyses conducted in the past. Marine teleosts swallow rather large quantities of water, which freshwater fishes do not; therefore results of tests conducted on freshwater forms cannot apply to marine species.

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Some Echo-Sounding Experiments on Fish.

By

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SINCE the autumn of 1949, experiments have been carried out from Lowestoft by myself and I. D. Richardson to find whether or not there was a best frequency to be used by echo-sounders for a given size of fish. The approach has been empirical because I am a biologist and not a physicist, and I am grateful to Mr. Halliday, of Messrs. Kelvin Hughes, Ltd., and Mr. B. C. Browne, of the Department of Geodesy and Geophysics, Cambridge, for their help as physicists.

In the first experiments carried out in December 1949, two echo-sounders were mounted alongside each other in the R. V. "Sir Lancelot"; one transmitted at a frequency of $14^1/_2$ kc./s. and the other at 30 kc./s. They were commercial models and differences in their power output were compensated for by transmitting through steel plates of different thicknesses; their beam angles were the same. Observations were made on herring shoals off the Ridens de Calais, both machines transmitting simultaneously on the same fish shoal. The records obtained were laid side by side and the number of soundings on fish for a given period of time with each machine was noted; thus we were concerned, not with the intensity of signal received from fish, but with the presence or absence of signal from fish in each sounding. We found that we obtained $1^1/_2$—2 times as many soundings on herring, using 30 kc./s., as we did when using $14^1/_2$ kc./s. Similar experiments on cod shoals off Bear Island showed that $2^1/_2$—3 times as many soundings were received with 10 kc./s. than with $14^1/_2$ kc./s. We felt that these results justified further work.

The second series of experiments was carried out in Windermere, so that we could hang fish below the echo-sounder and not have them drifted away from the sound beam by the tidal stream. Dead cod and herring, without their guts or air-bladders, were hung from net stretched across an aluminium frame; the frame was lowered from an anchored pontoon to the various depths of observation. Signals were presented on a cathode-ray tube (CRT) and were measured by matching against signals

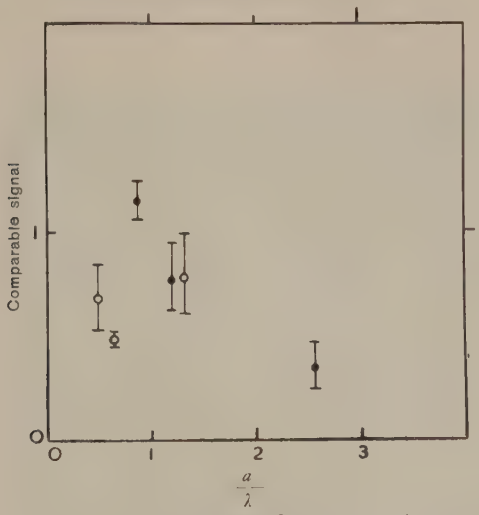

Figure 1. Relation beween the average signal from one fish and $\frac{d}{\lambda}$.

Cod are represented as black circles and herring as open circles. — d is the dorsiventral dimension of the fish and λ is the wavelength of the sound used.

injected in series with the receiving transmitter. Transmissions on any one set of fish at any one depth were made on 3 frequencies, 10, 14, and 30 kc./s.; these were calibrated relatively by comparing amplitudes from transmissions in a testing tank.

The disadvantage of this experimental arrangement was that the received signal was complex, components being returned from fish, frame, and ropes. Hence it was necessary to measure, not only the amplitude of the signal, but also its distribution in time; from the total amplitude, the amplitude due to frame and ropes was subtracted, leaving that due to fish. The actual formula used was $\sqrt{(A_T^2 \cdot t)} - (A_F^2 \cdot t)$ where A_T is the total amplitude, A_F the frame amplitude in μv., and t the time, in millimetres. Regressions of received signal in *amplitude* × *time* on numbers of fish at each depth were calculated; linear regressions were used because there were not sufficient observations to distinguish statistically between linear and square-root regressions. Also, it was not clear that the latter were really theoretically more correct than the former, as might be expected. From these statistics an estimate of the signal from one fish (cod or herring) was derived; similarly an estimate of the error was made. As three frequencies were used on two fish species, six observations were available; these, with their errors, are shown in Figure 1.

In Figure 1 the signal from one fish, divided by the relative calibration value, is plotted against $\frac{d}{\lambda}$, where d is the maximum dorsiventral dimension of the fish and λ the wave-length of the sound employed. There are two points to notice, namely:—

(a) that when $\frac{d}{\lambda}$ is about unity, maximum signal is returned from the fishes, and

(b) that there are marked differences between frequencies for either species, that lie outside the standard deviations of the observations.

The dorsiventral dimension of the fish was used because this is the dimension along which the wave-front travels, when the fish are swimming. This is not associated with any theoretical formulation, but is a function of any dimension that is likely to be relevant, e.g., the size of the fish or the curvature of its dorsal cross-section.

The Windermere experiments also included a number in which artificial air-bladders were hung alongside the fish. It was assumed that an air-bladder occupied 5 % of the fish's volume (Jones and Marshall, 1953); they were made up from rubber balloons. They had not the shape of fish air-bladders, being spherical, and the signal was returned, not from a flesh/air interface, but from a water/air interface. With the methods described above, it was found that 30—75 % of the signal was returned from the air-bladder.

The experiments carried out in Windermere suggested that a signal received from fish was composed of two parts, that due to the air-bladder and that due to the fish. As the size of the air-bladder is proportional to the size of the fish, any differences between frequencies observed at sea might be related to either or both factors. However, the results as presented could not be applied directly to signals from fish shoals in the sea because our shoals of dead fish in Windermere were artificially arranged and bore no relation to the shoaling density of fish in the sea. Again, it is possible, though improbable, that the effects described were a consequence of the system of measurement. Therefore it has been necessary to check that differences between frequencies are found at sea on identified shoals of fish.

For this purpose a triple-frequency echo-sounder was designed. A transmission was made every $\frac{1}{3}$ second on 10 kc./s., 14 kc./s., and 30 kc./s., calibrated transducers being used. The records were presented on a CRT, the time base of which was triggered by a switch on the echo-sounder. The time bases for the different frequencies were separated in the Y dimension on the screen by applying a positive voltage to the X plates for 10 kc./s., none for 14 kc./s., and a negative voltage for 30 kc./s. Thus, within one second the successive transmissions appeared above one another on the screen; the shutter of the oscilloscope camera was arranged to be open for one second, during which all three transmissions appeared on the screen. Thus the negative presented the records,

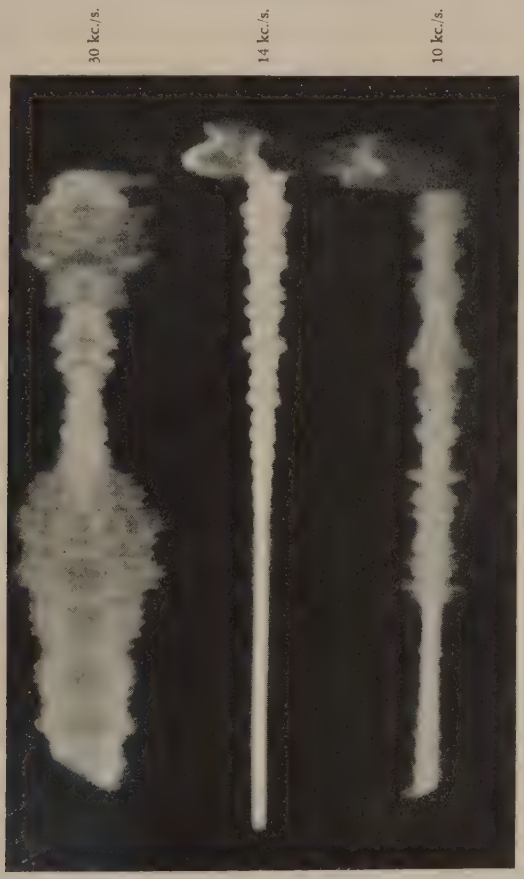

Figure 2. Photographic record of fish shoals from the triple-frequency sounder.
Three time bases are shown, one for each frequency used, 10 kc./s., 14 kc./s., and 30 kc./s. On the right of each time base, signals of strong amplitude from the bottom are shown. Fish shoals are shown as signals of somewhat weaker amplitude along the time bases (i.e., above the bottom).

as if simultaneously (Figure 2). Writing speeds of 50 and 15 milliseconds were used, which meant that any record measured about 20 fathoms or 6 fathoms of depth, respectively.

Outboard transducers were used with the ship stopped and the fish shoal was identified as well as possible. Fish traces have many characters, in shape, distribution, depth, and size; it is thought that there is sufficient variation in fish behaviour within any one species to account for nearly

all the characters of fish traces. Thus it may be quite possible to say that many traces of a given character at a given time and place are due to a given fish species; but it is not possible to identify a particular fish trace with certainty as belonging to that species. In this work, a general identification was made by going to a position where the desired species was expected; observations with the triple sounder on particular fish traces were taken and then an attempt was made to identify them by capture.

Film records were projected and the areas of fish traces in amplitude and in depth were planimetered; with the use of records of signals injected at the time of observation, average amplitudes over 5 fathoms of depth were calculated. These were compared for each frequency, and ratios of signals at 14 and 30 kc./s. were calculated with respect to those at 10 kc./s. (frequency ratios).

Observations were made on cod shoals off Bear Island, herring shoals at Sandettié, herring shoals off the Northumberland coast, an unidentified fish trace between the Ruytingen Bank and the "Dyk" lightvessel, and an unidentified bottom layer in the western English Channel. The results, as compared with 10 kc./s. as unity, are given in Table 1.

Table 1. Frequency ratios from triple-frequency sounder results.

	10 kc./s.	14 kc./s.	30 kc./s.	Number of observations
Cod (Bear Island)	1	5·4	0·6	111
Herring (Sandettié)	1	2·9	9·2	52
Herring (Northumberland)	1	2·7	7·0	49
Trace ("Dyk" lightvessel)	1	10·0	4·5	83
Trace (Start Point)	1	?	1·8	93

The results show that marked differences between frequencies occur between different fish species. These differences are consistent, not only within one series of observations, but the ratios for herring are also fairly consistent for two widely different fisheries. It is possible that the unidentified traces are, at the "Dyk" lightvessel, whiting, and off Start Point, a layer of semi-benthic organisms, perhaps swimming crabs. Again, observations within these sets are consistent. Our results for cod are different from those in Windermere. The Windermere fish were 65 cm. long, whereas those found off Bear Island, when the triple-frequency sounder was used, were 54·2 cm. long (both measurements are averages).

Thus the original observations at sea were confirmed. It remained to find out whether the effect was one due to fish or one due to air-bladder. As the Windermere observations suggested that a frequency difference arose between fish of different sizes, without air-bladders, it was decided to investigate the properties of the fish. This was done by using plasticine fish models and an air transducer connected to the echo-sounder. As the speed of sound in air is about $\frac{1}{4.25}$ that in water,

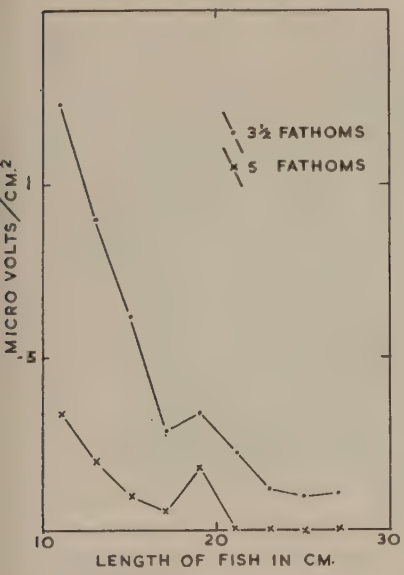

Figure 3. Signals from fish models of different sizes.
An echo-sounder was used in air; signals are expressed as μv. per cm^2. of cross-sectional area.

all dimensions of the models and their range from the transmitters could be reduced by that fraction. A series of fish models was made, scaled down quite accurately from taxonomic figures of cod and herring. Observations were made by pinning the fish model head downward on to a thin vertical brass rod, placed on the axis of transmission at given ranges. Thus, as the transducers were firing horizontally, the fish model took up a "swimming" position on the axis at a given range.

In the first experiment, signals were received from each of the series of fish models, at two ranges. The signals were measured, as before, by matching the observed signals against injected signals. The results, expressed as μv. per cm^2. of lateral cross-sectional area, are shown in Figure 3. There is a sharp decline in signal per unit area as the size of fish model increases. This means that at $3^1/_2$ fathoms the actual signal from a small model was larger than that from a larger one; at 5 fathoms, the signals were about the same in magnitude. It will be noticed that there is also a small peak at 19 cm., which is found at both ranges.

In the second experiment, a fish model was set up as before with head vertically downwards whilst the transmitter was rotated in the horizontal plane through the centre of the fish model's length. This procedure was repeated at a number of ranges; the results are shown in Figure 4, presented as a form of polar diagram. It will be seen that the half angle within which one fish model may be readily picked up is comparatively narrow. The half angle of the transmitter-receiver was about 16—18°. It was found that when the transmitter was translated in a plane parallel to that in which the fish model was "swimming",

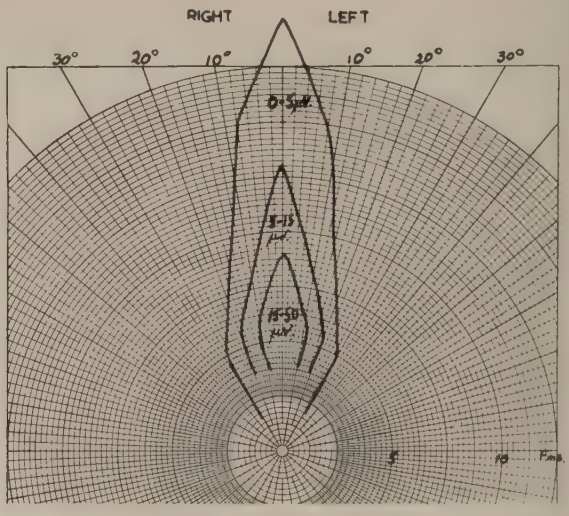

Figure 4. Polar diagram of signals received from a fish model in air.
The half angle of the directivity pattern of the transmitter-receiver system was 16°—18°.

the half angle was considerably larger, viz., about 45°. This is greater than can be accounted for merely in the directivity pattern of the transmission system. It will be noticed that the latter case is that which occurs in the sea, the translated transmitter being carried on a ship and the fish moving very slowly in relation to the ship's speed. Such a system is recorded on the echo-sounder as the well known "comet" trace; it has been a matter of common observation that some, although by no means all, comet traces imply a beam angle much wider than that expected from the directivity pattern of the transmission system.

In the third experiment, the fish model was rotated in the sound beam; it was stuck head down on the brass pin and the base for the pin was rotated horizontally. The results for two fish models are shown in Figure 5; it will be seen that in general strongest signals are returned from the sides of the model and that weakest signals are returned from its shoulders. In other words, in a quadrant from the dorsal aspect to the lateral aspect, strong signals were received at 0° and 90° (the latter from the lateral aspect being greater) and weak signals were received at 45°. Further points in comparison are that stronger signals are returned from the smaller fish and that the polar distributions of signals for the two dissimilar models are very different in shape.

The procedure described was repeated for a number of fish models. Figure 6 shows the relation between signals (as μv. per cm^2. of lateral

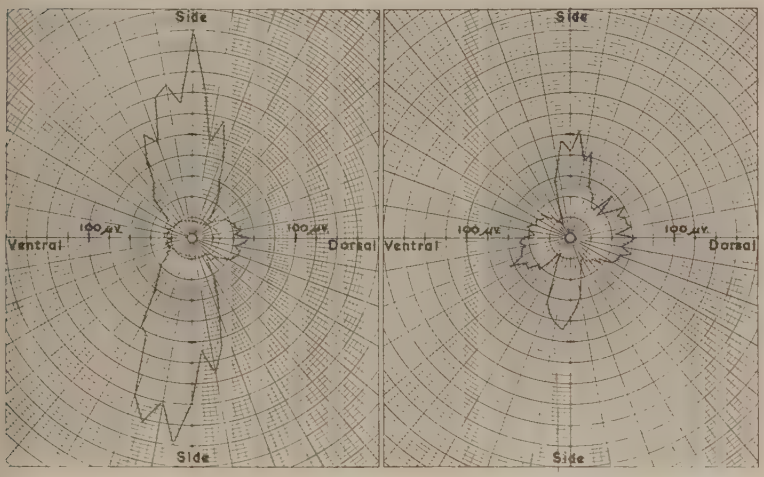

Figure 5. Signals received from a fish model rotated in a plane normal to the axis of transmission.
In the dorsal position, the fish model was scattering sound energy from its back.
(a) Fish model of 2·5 cm. diameter in the dorsiventral dimension.
(b) Fish model of 3·16 cm. diameter in the dorsiventral dimension.

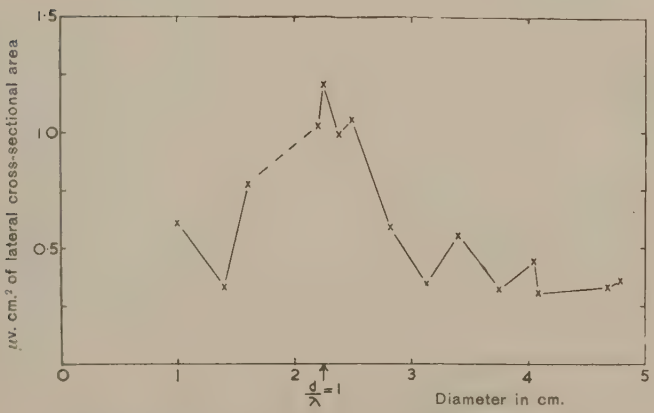

Figure 6. Signals received from fish models of different sizes.
The diameter, d, is the diameter in the dorsiventral dimension and λ is the wave-length of the sound used.

cross-sectional area) returned from the dorsal aspect of a fish model and its diameter in the dorsiventral dimension. It is confirmed that there is an effect in the shape of a fish which returns strongest signals to the receiver when $\frac{d}{\lambda}$ is about equal to one.

Analogous to the curve shown in Figure 6, there are theoretical curves for scattering at 0° for a sphere and a cylinder. Each shows a series of maxima and minima of received signal as $\frac{2\pi \cdot r_0}{\lambda}$ increases (where r_0 is the radius of the sphere or the cylinder). The curve for a cylinder shows that as $\frac{2\pi \cdot r_0}{\lambda}$ increases, the differences between maxima and minima decrease. A fish model is a much more complex shape than either sphere or cylinder, and the theoretical formulation for scattering from such a shape is considerably more difficult.

The experiments just described are of the same character as those carried out in Windermere. The question is, How far do they account for results obtained with the triple-frequency sounder? Nearly all the results from the air sounder were expressed as μv. per cm^2. of lateral cross-sectional area. In the sea, however, if all fish were packed at equal density per unit volume, the correct expression would be as μv. per fish. Then it is unlikely that any very marked differences in frequency would become manifest, as indeed is the case if the signals from the models in Figure 3 are compared as μv. per model and not as μv. per cm^2. of lateral cross-sectional area. However, it is probable that the shoaling density of fish species per unit volume is inversely proportional to their size; if that is the case, then the expression μv. per cm^2. of lateral cross-sectional area again has some validity.

We have a little evidence that the shoaling density per unit volume decreases with increased size. The results from the triple-frequency sounder were expressed as average amplitudes over a number of observations; hence, from the results it was possible to extract a coefficient of variation. If there were few fish in the shoal examined, the coefficient of variation might be high; if, however, there were many fish in the shoal, the coefficient might be low. Our results with the triple sounder have shown that the coefficient of variation, from records of cod shoals, was 40—60 %, whereas that for herring was 10—20 %. These results are significant and indirectly support the contention that shoaling density per unit volume is inversely proportional to the size of the fish.

The consequences of the experiments described seem to be as follows:—

(1) The theoretical formulation for the scattering of sound from an ideal fish is conceivable, though difficult.

(2) The acoustic qualities of fish materials, scales, flesh, and bone need investigation.

(3) It will be necessary to find the shoaling densities of different fish species under different conditions. Also it will be necessary

to arrive at some estimates of shoal sizes under different conditions.

(4) The part played by the air-bladder needs investigating. If one combines the results from the triple-frequency sounder with those from the air sounder, it seems that the air-bladder may "underline" the differences in size of fish. As most air-bladders will be smaller than $\frac{\lambda}{4}$ and as their sizes are proportional to those of the fish, this possibility is not unlikely.

From work carried out along these lines it might be possible to devise acoustic gear that will make estimates of the sizes and numbers of fish. The preliminary results along these lines with the triple-frequency sounder indicate that a high degree of discrimination might, in the end, be possible.

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Selection of Soles by the Mesh of Trawls.

By

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Introduction.

In the trawl fisheries of north-west Europe the sole (*Solea vulgaris*, Quensel) is of unique importance for two reasons. Firstly, the sole is, in almost all countries where it is available, the most highly esteemed of fishes and therefore commands the highest market prices. Secondly, the natural habitat of the sole is in seas within the area of enforcement of the 1946 International Overfishing Convention, where it occurs freely mixed with other protected species such as plaice, which have considerably different escape lengths from any one size of mesh.

Of the total fish landings in north west Europe the sole constitutes 0·4 % by weight, although its contribution to the total value of all fish landed is 1·5 %. The sole makes up about 4 % of the demersal catches in the seas adjacent to England and Wales, where, generally speaking, it is a very important secondary species in the catch of most trawlers; the quantity of soles in the catch of any one trawler is frequently a deciding factor in whether its fishing has been profitable or otherwise. But many of the trawlers of Belgium fish primarily for soles, and so do some of the near-water trawlers of Holland, England, and Wales at certain seasons. Belgian trawlers caught 26·5 % of all soles in 1951 and these constituted 11·5 % of the total Belgian catch of fish; furthermore, they contributed as much as 27·3 % of the total value of all Belgian fish.

The ability of a sole to squeeze its way through an opening such as a mesh, apparently small enough to prevent its passage, is well known. Amongst flatfish the sole is a great contortionist whose progress through constricting apertures is aided and made practically irreversible by its coating of small stiff scales. Relative to other flatfish, its features of small head, body somewhat constrictable, with a high length to constricted width ratio, and very flexible body, with small bones and much muscle, at once contribute to its market value and to its ability to escape through meshes of nets. A mesh just preventing the escape of a certain sized plaice will allow a considerably larger sole to escape, while it is unfortunately also the case that, at the smallest size at which each is suitable for table use, the plaice is longer than the sole.

The best standard measure of mesh is that by a gauge 2 mm. thick inserted into the lumen of the stretched mesh when the mesh is still wet after use; the measurement so obtained is of the actual size of mesh irrespective of knot size, looseness of knots, shrinkage and stretching, and is an indication of the space available for fish to escape through. For instance, in a mesh measuring 70 mm. on the gauge the perimeter of escape space or lumen will be 144 mm. compiled as twice the gauge reading plus 4 mm. for twice the thickness of the gauge. The cod-end mesh sizes to be referred to in the present work will be those "on the gauge" measured as above, the single figures quoted being the average of a number of measurements throughout the cod-end; the gauge used was simple, not spring loaded, and was pushed into the meshes with gentle force of perhaps up to 5 lb.

Past experiments.

The complication of mesh regulation by the sole's ability to escape when other fish are retained has long been recognized but there are few established data relating the size of escaping soles and the size of mesh.

Gilson, reported by Kyle (1905), made a covered-net experiment using a small inshore beam-trawl with cod-end mesh-size recorded as 2—2·5 cm. measured along one side of the mesh. In converting this "bar" measurement to an "on the gauge" measurement, it is assumed that the size quoted is the size at which the mesh fished and that the measurement was taken between centres of knots; then the size on the gauge will be the average, 2·25 cm., multiplied by two and less 5 mm. for knot size, i.e., 40 mm. His results for sole when graphed as the percentage at each centimetre length retained in the cod-end appear as a fairly smooth ogive with 50 % point (indicating at what length half of the fish will escape and half be retained) at 12·0 cm. This should perhaps be corrected to 12·5 cm. to allow for measurements probably being made to the nearest centimetre below the overall length of the fish. The simple proportionality factor relating mesh size (on the gauge) to length of fish at 50 % point for the sole, from these experiments, is 3·1.

Buchanan-Wollaston (1933) made an alternate-haul experiment with an inshore motor-trawler using a small-meshed ($2^1/_4$ inch) trawl alternately, first with a 3-inch-mesh trawl and then with a $3^1/_2$-inch-mesh trawl, the experiment being undertaken to obtain information about mesh selection of soles. The sizes of mesh used in this experiment were recorded simply as $2^1/_4$, 3, and $3^1/_2$ inches without any indication of the method of measurement being given; Davis (1934) identifies them as probably corresponding to some which he used of single cotton twine of weight about 196 yards per pound, the 3-inch and $3^1/_2$-inch netting being respectively of 25·3 and 20·7 rows per yard; but from recent (1954) verbal communication with Buchanan Wollaston I learn that the nets used were of single-braided moderately fine manila, or possibly hemp, but not cotton, and the meshes were measured when the netting was new by the use of a flat

gauge inserted into the lumina of a number of meshes scattered about the cod-ends.

By allowing 10 % reduction in size for shrinkage and other variable factors, it is roughly estimated that the 3-inch and 3½-inch meshes used by Buchanan-Wollaston fished at respective sizes of approximately 69 and 80 mm. on the gauge. Baerends (1947) quotes Buchanan-Wollaston's results, simply converting the original 3-inch and 3½-inch mesh-sizes to centimetres.

Buchanan-Wollaston's results for his 3½-inch mesh (80 mm. on the gauge) were good, the percentage of fish retained at each centimetre length of fish appearing as a smooth ogive when plotted. The 50 % point of the ogive lay at 30·6 cm. The ogive for the 3-inch mesh (69 mm. on the gauge) was not so smooth; although the 0 and 100 % escape points were clearly at 23·5 and 30·5 cm., the results within the critical length-range 24—28 cm. were not very satisfactory, but probably the best fit of a smooth curve to the data would be that showing a 50 % point at length 27·0 cm. By this interpretation of Buchanan-Wollaston's results, the simple proportionality factor relating mesh-size (on the gauge) to length of fish at 50 % point for the sole will be 3·9 for the 69 mm. mesh and 3·8 for the 80 mm. mesh.

Recent experiments.

The more recent experiments to be reported on here have been made from the large North Sea trawler "Sir Lancelot", a research ship of the Fisheries Laboratory, Lowestoft, on grounds normally fished by commercial deep-sea trawlers. In November 1953, a mesh experiment with covered cod-ends was carried out to obtain data primarily on sole. In 1948, a number of experiments were made, with the alternate-haul technique, to obtain data primarily on plaice; soles were caught incidentally and were measured, but in only one experiment were the numbers of soles sufficient for the data to be at all reliable for mesh selection purposes.

The trawls used in both 1948 and 1953 experiments were basically the same, differing only in detail of headline flotation and groundrope chaining. The specifications were as follows:— Lowestoft otter-trawl with otter-boards 9 ft. 6 in. × 4 ft. 8 in. towed by a 125 ft. steam trawler. Vigneron-Dahl (bridle) gear was not used.

Headline	80 ft.	
Groundrope	116 „	
Legs (wire and chain)	12 „	
Upper Wings	32 „	6 in. mesh
Lower Wings	66 „	5 „ „
Square	30 „	6 „ „
Belly	28 „	5—3½ in. mesh
Cod-end	21 „	

All the netting was made of untreated 3-ply sisal twine, the wings, square, and belly being of single twine running 112 yds. per pound weight, and the cod-ends of double twine running 125 yds. per pound.

The mesh-sizes quoted are measured by the British net-makers' method as distance between opposite knots when stretched, of new netting, including one knot and excluding the other.

The wing-pieces of the groundrope were of wire heart surrounded by packing and wound with rope to a total diameter of $3^1/_2$ inches, and were, in parts, loosely wound with small chain. The 20-ft. bosom was, in the 1953 experiments, fitted with wooden bobbins. A tickler chain, fitted between otter-boards, was used for all but one of the hauls, and during part of the 1953 experiment an additional small tickler across the front of the groundrope bosom was also used. Towing speed of about $2^1/_2$—3 knots and warp lengths about three times the water depths were those as used by most commercial trawlers.

1953 Covered-net experiment.

The investigation of trawl mesh selection of soles was the main object of the 1953 experiment. The cod-end cover used was of shrimp-netting, mesh-size 80 rows to the yard, attached over the top (dorsal) side of the cod-end only; the bottom half of the cod-end (ventral) was not covered, but was fitted with "false bellies" (or "rubbers"), nor were cane supports for the cover netting used. The cover was attached along all four edges of the top half of the cod-end, and was of such a size and shape that its netting was slacker than that of the cod-end and that a tapered pocket overhung the extreme distal end of the cod-end by at least 3 feet; fish escaping the cod-end collected in this pocket.

Hauls, each of $2^1/_2$ hours duration, were made with three different cod-ends in both daylight and darkness during November under a variety of weather conditions ranging from calm to rough. All hauls were made approximately on the same ground off the Suffolk coast near the Gabbards. The ground was rather rough with masses of the tube-worm (*Sabellaria*) occurring commonly.

The three cod-ends used were of mesh-sizes 67·4, 73·7, and 86·5 mm. on the gauge measured when wet. These sizes are quoted as the averages of all measurements made; samples each of 20—30 meshes chosen randomly from the top half of the cod-end were measured at intervals during the experiment. The average mesh-size of any one cod-end did not alter appreciably during the experiment, the cod-ends having been shrunk before use (Table 1).

The numbers of hauls made with each cod-end were, respectively, 8, 14, and 12. When the trawl was hauled, the contents of the cod-end and the cover were both released and sorted separately; the catch was recorded and the overall lengths of all soles measured to the nearest centimetre below, while the fish were still fresh and ungutted. Fish actually meshed in the cod-end, even if lightly held by the meshes and easily pulled through, were included in the catch of the cod-end and not that of the cover, since in ordinary trawling they would have been included in the catch brought on deck.

The length distributions of all soles caught in the cod-ends and covers, together with the total population dealt with, are tabulated in Table 2

Table 1. Mesh-sizes, on the gauge, of three cod-ends used in a covered-net experiment, 1953.

Mesh-size mm.	Number of Meshes; Cod-end A	B	C
60	2	—	—
61	—	—	—
62	2	—	—
63	1	—	—
64	6	—	—
65	12	—	—
66	4	—	—
67	11	—	—
68	5	—	—
69	5	2	—
70	15	11	—
71	2	13	—
72	3	7	—
73	—	17	—
74	—	38	—
75	2	29	—
76	—	12	—
77	—	4	—
78	—	4	—
82	—	—	1
83	—	—	—
84	—	—	8
85	—	—	33
86	—	—	16
87	—	—	19
88	—	—	14
89	—	—	11
90	—	—	8
Average Mesh-size mm.	67·4	73·7	86·5

and graphed in Figure 1. It will be seen that the soles available and entering the trawl were of excellent size for mesh-experiment purposes, the majority of them being well distributed over the length-range 18—35 cm. with the biggest mode at about 24 cm.; brood soles of length 12—17 cm. with mode at 14 cm. were also present. The total numbers of soles caught per haul varied between 31 and 155 for the 67·4 mm. mesh, 80 and 278 for the 73·7 mm. mesh, and 33 and 180 for the 86·5 mm. mesh.

Of the other species of fish caught simultaneously with the soles and likely to affect the mesh selection by blocking some meshes to the soles, the most bulky were rays, of which, on the average, about 50 were caught per haul; about half of these were very small. Dogfish numbered about 20 per haul and small whiting occurred in the cod-ends in

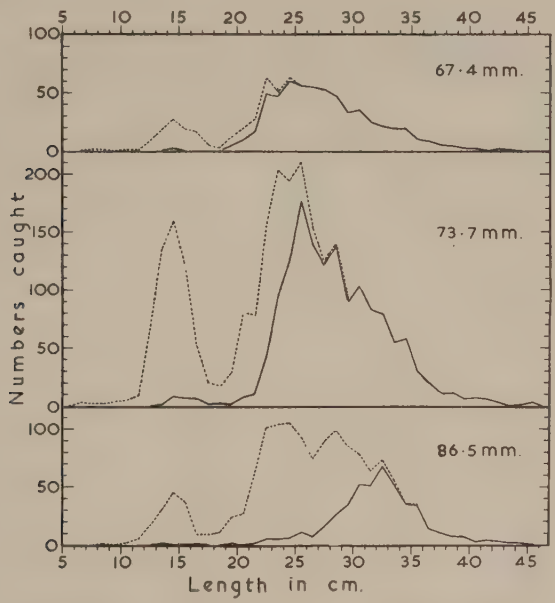

Figure 1. Length distributions of soles caught in covered-net experiments, 1953, using three sizes of cod-end mesh. Dotted line indicates fish entering cod-end. Entire line indicates fish retained by cod-end.

quantities varying between 10 and 80 per haul while greater numbers passed into the covers. The rest of the cod-end catch per haul typically consisted of about 3 cod, 1 turbot, 15 lemon soles, 5 plaice, 15 pout whiting, and 3 gurnards. Lumps of *Sabellaria* were also caught, sometimes in quantities as great as two fish-baskets full per haul although the average quantity was somewhat less than one basket per haul.

When the number of soles retained by the cod-end is expressed as a percentage of the number entering the cod-end (Table 3), and the percentage retained at each centimetre length of fish, with an allowance of +0·5 cm. for the method of measuring, is plotted for each cod-end mesh-size as in Figure 2 A, it is apparent that the data provide reliably smooth selection curves with well defined middle sections in which lie the "50 % points", or lengths at which half the fish entering the cod-end are retained and half escape. Furthermore, the 50 % point for each of the three meshes lies well within the length-range in which the available fish were most numerous. For each cod-end the selection was fairly sharp, the transition from 10 % to 90 % retained being accomplished within a 6 cm. range of length.

The apparent 50 % points from first inspection of the data are at 20·7 cm. for the 67·4 mm. mesh, 23·7 cm. for the 73·7 mm. mesh, and 29·9 cm. for the 86·5 mm. mesh.

Table 2. Length distribution of soles caught in cod-ends and in cod-end cover netting, 1953 experiments.

Mesh-size	67.4 mm.		73.7 mm.		86.5 mm.	
Number of hauls	8		14		12	
Length (cm.)	Cod-end	Cover	Cod-end	Cover	Cod-end	Cover
6	—	—	—	3	—	—
7	—	1	—	2	—	—
8	—	1	—	2	—	1
9	—	—	—	4	—	—
10	—	1	—	5	—	2
11	—	1	—	9	—	5
12	—	9	—	69	—	17
13	—	19	1	135	1	29
14	2	25	8	151	—	45
15	—	19	7	114	1	36
16	—	16	6	46	1	8
17	—	5	1	19	—	9
18	—	3	2	15	—	11
19	4	8	1	28	2	22
20	9	10	7	73	—	27
21	16	11	10	68	2	61
22	49	14	43	114	5	96
23	47	4	93	110	5	99
24	60	3	125	69	6	99
25	56	—	176	34	10	83
26	55	—	139	14	7	67
27	53	—	122	3	15	74
28	47	—	139	1	25	74
29	33	—	89	2	34	51
30	35	—	103	—	51	27
31	25	—	83	—	51	13
32	21	—	79	—	67	6
33	19	—	55	—	53	3
34	19	—	57	—	36	—
35	10	—	30	—	34	1
36	8	—	20	—	14	—
37	5	—	10	—	10	—
38	4	—	11	—	7	—
39	2	—	6	—	7	—
40	2	—	7	—	3	—
41	—	—	6	—	4	—
42	2	—	3	—	3	—
43	1	—	—	—	2	—
44	—	—	1	—	2	—
45	—	—	3	—	—	—
Total	584	150	1,443	1,090	458	966

Table 3. Observed and adjusted percentages of soles at each centimetre length retained by cod-end meshes, 1953 experiments.

Mesh-size	67.4 mm.		73.7 mm.		86.5 mm.	
Length	% retained		% retained		% retained	
cm.	Observed	Adjusted	Observed	Adjusted	Observed	Adjusted
6	—	—	0	0	—	—
7	0	0	0	0	—	—
8	0	0	0	0	0	0
9	—	—	0	0	—	—
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0·7	0·5	3·3	2·2
14	7·4	5·1	5·0	3·4	0	0
15	0	0	5·8	3·9	2·7	1·8
16	0	0	11·5	8·0	11·1	7·7
17	0	0	5·0	3·4	0	0
18	0	0	11·8	8·2	0	0
19	33·3	25·0	3·4	2·3	8·3	5·7
20	47·4	37·5	8·8	6·0	0	0
21	59·3	49·2	12·8	8·9	3·2	2·1
22	77·8	70·0	27·4	20·1	5·0	3·4
23	92·2	88·7	45·8	36·0	4·8	3·3
24	95·2	93·0	64·4	54·7	5·7	3·9
25	100·0	100·0	83·8	77·5	10·8	7·4
26	100·0	100·0	90·8	86·9	9·5	6·5
27	100·0	100·0	97·6	96·4	16·9	11·9
28	100·0	100·0	99·3	98·9	25·3	18·4
29	100·0	100·0	97·8	96·7	40·0	30·8
30	100·0	100·0	100·0	100·0	65·4	55·7
31	100·0	100·0	100·0	100·0	79·7	72·3
32	100·0	100·0	100·0	100·0	91·8	88·2
33	100·0	100·0	100·0	100·0	94·6	92·2
34	100·0	100·0	100·0	100·0	100·0	100·0
35	100·0	100·0	100·0	100·0	97·1	95·8
36	100·0	100·0	100·0	100·0	100·0	100·0
37	100·0	100·0	100·0	100·0	100·0	100·0
38	100·0	100·0	100·0	100·0	100·0	100·0
39	100·0	100·0	100·0	100·0	100·0	100·0
40	100·0	100·0	100·0	100·0	100·0	100·0
41	—	—	100·0	100·0	100·0	100·0
42	100·0	100·0	100·0	100·0	100·0	100·0
43	100·0	100·0	—	—	100·0	100·0
44	—	—	100·0	100·0	100·0	100·0
45	—	—	100·0	100·0	—	—
Total	79·6	72·2	57·0	46·9	32·2	24·0

Factors influencing the validity of the results include the escape of soles through parts of the cod-end other than the covered top side, and the re-entry of fish from the cover into the cod-end. Both of these

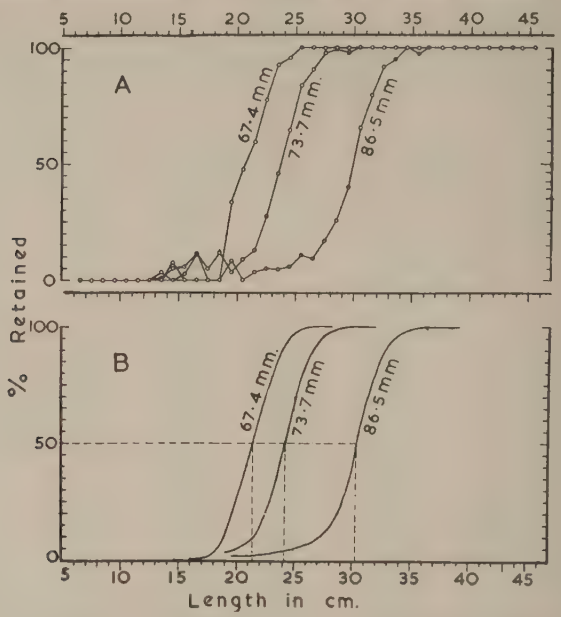

Figure 2. Percentages of soles at each length retained by 67·4, 73·7, and 86·5 mm. double-sisal trawl cod-ends (covered-net experiments, 1953).
A. Observed percentages.
B. Smooth curve, fitted by eye, to adjusted percentages (see p. 285).

happenings were observed during the course of the experiment; from the frequency of its observed happening the re-entry factor is considered to be so small as to be safely neglected, but the escape of soles from the uncovered bottom half of the cod-end is frequent and should be allowed for in determining the true 50 % selection points. The meshing of soles in the bottom half of the cod-end was common and, after hauling, several soles were retrieved from the protective false bellies on the underside of the cod-end, having escaped through the bottom half of the cod-end only to enmesh themselves in the old netting used as false bellies. If the size selection of fish by meshes was absolutely sharp, all fish below the selection point escaping and all above being retained, then the escape of fish from the bottom half of a cod-end during a mesh experiment would not be of any consequence. But as there is actually a definite graduation in the selection, then the 50 % point is affected by such unrecorded escapes. However, since the slope of the plotted ogive at the 50 % point is not very steep (Figure 2 A) the maximum error, which will occur when it is assumed that as many fish escape through the bottom side of the cod-end as escape through the top side into the cover, must be that the apparent 50 % point is about 0·7 cm.

too low. From the observed relative numbers of soles meshed in the top and bottom sides of the cod-end and from a consideration of the cross-section shape of the cod-end in action as a somewhat flattened oval with the central part of the bottom half resting on the sea bed, a reasonable guess would be that half as many soles escape the bottom half of the cod-end as escape the top half; this allowance is higher than would be deduced from T o d d' s (1911) results, which showed only 20 % of the dabs and 7 % of the plaice escaping from the forward part of the cod-end as doing so through the underside. Therefore, to allow for this, the numbers caught in the cover have been raised by 50 % and the percentages retained re-calculated (Table 3) and re-plotted (Figure 2 B). The 50 % selection points of the three meshes are then shown to be at 21·4 cm. for the 67·4 mm. mesh, 24·2 cm. for the 73·7 mm. mesh, and 30·3 cm. for the 86·5 mm. mesh. The respective proportionality factors relating the mesh-sizes to their 50 % selection lengths are 3·2, 3·3, and 3·5.

The quantities of *Sabellaria* (commonly called "ross" by British fishermen) and other fish caught might have been expected to affect results by blocking some meshes against the escape of soles, but no obvious differences are discernible between the length distributions of soles in those hauls with less and in those hauls with more *Sabellaria* and other fish.

1948 Alternate-haul experiment.

Data on trawl mesh selection of soles were collected incidentally in this experiment, which was carried out primarily as a mesh experiment on plaice. In all, three cod-ends were used, one of very small mesh, average size 43 mm., to determine the fish population present, one of average mesh-size 71·7 mm. (see Table 4), and a third of average mesh-size 111 mm. The cod-ends were used in repeated series on the same trawl, the hauls with each being of three hours duration. As the numbers of soles of length around the selection range of the 111 mm. cod-end were too small to provide useful results, only the selection of the 71·7 mm. cod-end will be considered.

In all, seven pairs of hauls were made on the Texel Ground under fine weather conditions. The total numbers of soles at each centimetre length (measured to the centimetre below) caught by each cod-end and the percentage retained by the 71·7 mm. cod-end are shown in Table 5. As the numbers were small, the length distributions were smoothed and the percentages retained were then calculated on the assumption that the catch of the small-mesh cod-end represents the true population present and the catch of the 71·7 mm. cod-end only a selection of the true population. A typical catch of the 71·7 mm. cod-end was, besides the few soles, 670 plaice of length mostly 15—25 cm., 420 dabs of length 15—20 cm., 2 turbot, 10 small brill, 1 cod, and 30 gurnards. The data are plotted and a smooth ogive fitted by eye in Figure 3. This shows the 50 % point for the 71·7 mm. mesh to be at 23·3 cm. Thus the proportionality factor relating mesh-size and selection point is 3·25.

Table 4. Mesh-sizes, on the gauge, of two cod-ends used in an alternate-haul experiment, 1948.

	Cod-end D		Cod-end E	
	Mesh-size mm.	Number of meshes	Mesh-size mm.	Number of meshes
	36	2	66	2
	37	1	67	4
	38	12	68	12
	39	21	69	19
	40	32	70	75
	41	34	71	26
	42	35	72	35
	43	36	73	5
	44	35	74	16
	45	42	75	19
	46	18	76	10
	47	8	77	8
	48	11	78	8
	49	3	79	—
	50	7	80	1
	51	—	—	—
	52	—	—	—
	53	—	—	—
	54	2	—	—
	55	1	—	—
Average mesh-size mm.	43·0	—	71·7	—

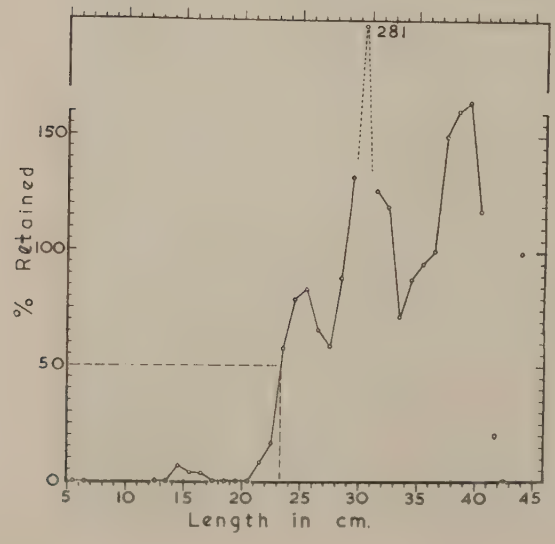

Figure 3. Percentage of soles at each length retained by 71·7 mm. double-sisal trawl cod-end (alternate-haul experiment, 1948).

Table 5. Length distributions of soles caught in 7 hauls with each cod-end in an alternate-haul experiment, 1948, and percentage at each length retained by a 71.7 mm. mesh.

Mesh-size	43.0 mm.		71.7 mm.		% retained by
Length	Numbers		Numbers		71.7 mm.
cm.	Actual	Smoothed	Actual	Smoothed	mesh.
4	—	0·3	—	—	0
5	1	0·3	—	—	0
6	—	0·3	—	—	0
7	—	—	—	—	—
8	—	—	—	—	—
9	—	—	—	—	—
10	—	—	—	—	—
11	—	—	—	—	—
12	—	0·3	—	—	0
13	1	1·0	—	+	0
14	2	4·7	—	0·3	6·4
15	11	8·3	1	0·3	3·6
16	12	8·7	—	0·3	3·4
17	3	5·0	—	+	0
18	—	1·3	—	—	0
19	1	0·7	—	—	0
20	1	2·3	—	—	0
21	5	3·7	—	0·3	8·1
22	5	4·3	1	0·7	16·3
23	3	4·7	1	2·7	57·4
24	6	8·0	6	6·3	78·8
25	15	10·0	12	8·3	83·0
26	9	12·7	7	8·3	65·4
27	14	10·3	6	6·0	58·3
28	8	8·3	5	7·3	88·0
29	3	5·3	11	7·0	132·1
30	5	3·3	5	9·3	281·8
31	2	5·3	12	6·7	126·4
32	9	6·7	3	8·0	119·4
33	9	8·0	9	5·7	71·2
34	6	8·0	5	7·0	87·5
35	9	5·3	7	5·0	94·3
36	1	4·0	3	4·0	100·0
37	2	2·0	2	3·0	150·0
38	3	2·3	4	3·7	160·9
39	2	2·0	5	3·3	165·0
40	1	1·7	1	2·0	117·6
41	2	1·3	—	0·3	23·1
42	1	1·0	—	—	0
43	—	0·3	—	0·3	100·0
44	—	—	1	0·3	—
45	—	—	—	0·3	—
Total	152		107		70·4

Table 6. Summary of mesh selectivity factors for sole from various experiments.

Experiment	Mesh-size mm.	50% length cm.	Factor
Gilson, 1905	40	12·5	3·1
1953 covered net	67·4	21·4	3·2
Buchanan-Wollaston, 1933	69	27·0	3·9
1948 alternate haul	71·7	23·3	3·25
1953 covered net	73·7	24·2	3·3
Buchanan-Wollaston, 1933	80	30·6	3·8
1953 covered net	86·5	30·3	3·5

Discussion.

Available sole mesh selection results are summarized in Table 6.

The results from the 1948 and 1953 experiments with a large trawl and involving four cod-ends, all of different mesh-sizes, and those from Gilson's (1905) beam-trawl experiments (which, however, must be treated with some reserve) together form a natural sequence, with the 50 % selection lengths increasing with increase in mesh-size. Similarly, the proportionality factors relating mesh-size and 50 % selection lengths are ranged in ascending order with increase in mesh-size. The two more likely causes of the apparent gradual increase in factor with increase in mesh-size are, firstly, that the larger mesh is much more flexible than the smaller mesh of the same twine, the rather rigid knots remaining the same size and only the length of the more flexible part of the mesh, — i.e., the twine between knots — changing with mesh-size; and, secondly, that the fish at the 50 % selection length of the larger mesh are relatively stronger and presumably more able to escape through meshes than those at the 50 % selection length of the smaller mesh.

But the results obtained by Buchanan-Wollaston do not seem to agree very well with those from the more recent series. By comparison, his 50 % lengths for 69 and 80 mm. cod-ends are 4·9 cm. and 3·4 cm. higher than would have been expected for the same size of mesh in a double-braided manila or sisal trawl cod-end. A part of the 4·9 cm. difference may be due to wrong interpretation of the actual 50 % point of the 69 mm. mesh; a part of both differences may be due to making too high an allowance for change in mesh-size with use, although Buchanan-Wollaston, again verbally, agrees that some shrinkage must have occurred. An important part of the discrepancy is likely to be due to the factors of flexibility of material used in making the cod-ends and of speed of towing the net. The more flexible the netting, the larger will be the fish just able to escape. A cod-end of single-braided twine will have more flexible meshes than one of the same mesh-size double braided, as the side knots will be smaller; Buchanan-Wollaston used single twine probably of a thinner gauge than that used double in the later experiments. The slower a trawl is towed, the more flexible its netting is allowed to be when in action; Buchanan-Wollaston's experiments were carried out from a small inshore trawler towing at no more than 2 knots

whereas the later experiments have been carried out from a powerful steam trawler at about 3 knots.

If we now turn to the first effect on sole catches of the Overfishing Convention, under which a minimum trawl-mesh-size of 75 mm. on the gauge was brought into force in 1954, the recent experiments indicate that a mesh selectivity factor of about 3·3 should apply for a double-braided sisal or manila trawl cod-end. This would mean that the appropriate selection ogive would have a 50 % point at 25·0 cm.; the 10 % and 90 % retained points would be at about 23·0 and 27·0 cm. respectively. Thus, nearly all soles of length less than 23 cm. will escape, most of those longer than 25 cm. will be retained, and although a very few will escape, nearly all those longer than 27 cm. will be retained. The 50 % selection length for sole of a similar cod-end of average mesh-size 80 mm. on the gauge will be 27·2 cm.

Summary.

1. Published results of experiments investigating the selection of soles by trawl meshes are reviewed.
2. Original data from recent experiments on mesh selection of soles by trawls with double-braided sisal cod-ends are presented.
3. The 50 % selection lengths determined for three double sisal trawl cod-end mesh-sizes by covered-net experiment are 21·4 cm. for 67·4 mm. mesh, 24·2 cm. for 73·7 mm. mesh, and 30·3 cm. for 86·5 mm. mesh. By an alternate-haul experiment the 50 % selection length of a 71·7 mm. double sisal mesh was determined as 23·3 cm. Mesh-sizes are quoted as "on the gauge".
4. The factor 50 % length ÷ mesh-size is found to increase with increasing mesh from 3·2 for a 67 mm. mesh to 3·5 for an 86 mm. mesh. It is suggested that the main cause of this is change in flexibility of the mesh with change in mesh-size. The discrepancy between these results and those of Buchanan-Wollaston is discussed.
5. The expected 50 % release length of a double-braided sisal trawl cod-end of mesh-size 75 mm. on the gauge is 25·0 cm.; that for an 80 mm. sisal cod-end is 27·2 cm.

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A Preliminary Report on a New Type of Commercial Escallop Dredge.

By

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THE optimum angle of attack of a dredge blade is the minimum which allows the catch to be lifted the necessary height to pass over the blade and into the bag. The standard escallop dredge used in Britain consists of a triangular frame of heavy iron, bent to an acute angle at the base, with a toothed blade attached to the bent portion, thus forming an acute angle with the main framework and with the bottom when the dredge is in operation.

In deep water it is difficult to determine the angle formed between the dredge blade and the bottom. When a sisal rope is used for towing, a backward curve is formed by the warp, resulting in a very shallow angle between the dredge blade and the bottom, but if the speed of tow is slightly increased, the resistance of the rope may lift the dredge off the bottom. The angle of the dredge frame in the water is also such that forward movement tends to lift the dredge. With a wire towing-rope, the weight of the warps is greater than the drag at low speeds and thus a forward catenary is formed. The dredge frame lies nearly parallel to the bottom, giving a steep angle of attack for the dredge blade. The tendency of the dredge to lift is reduced but passage of material into the bag is obstructed. If the wire is shortened, to give a satisfactory angle of attack, the dredge again tends to lift.

Recent underwater observations of the standard Irish escallop dredge, which has a toothed bar, showed that the dredge travelled along the bottom in a series of shallow leaps. This skipping resulted presumably from the digging of the teeth, followed by the stretching of the warp until the tension was sufficient to pull the teeth out of the sand, and then by the descent of the dredge to the bottom again as the tension slackened and the speed of the dredge through the water was reduced. This would probably occur in deep water even with wire warps, as the catenary would result in considerable spring.

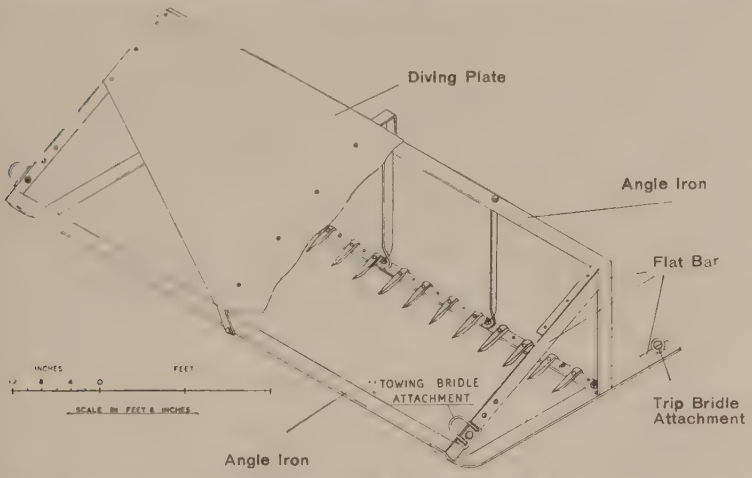

Figure 1. Isometric projection of dredge with diving plate cut away to show detail of dredge bar construction and bracing members from angle iron to bar.

A further disadvantage of the standard dredge is that by its shape it makes a very efficient grapple and may foul any steep projection or piece of wreckage on the bottom.

It is considered that the dredge described below overcomes these disadvantages and has additional minor advantages. A standard dredge blade with teeth is mounted on 2 in. × 1/4 in. flat iron runners, 3 ft. long, which curve upwards to a height of 4 in. at the leading edge. The blade is mounted so that the teeth project about 1/2 in. below the bottom edge of the runners. This projection is considered sufficient to lift most escallops, which normally lie with the curved valve recessed in the sand and the flat valve level with the bottom, the flat valve sometimes being covered with a fine layer of deposit. The runners are joined by an angle-iron bar across the leading edge and by two bars, mounted vertically, one at each end of the blade, rising to a height of 1 ft. 6 in. and joined horizontally at their upper ends by a 2 in. angle-iron bar. This upper horizontal bar is in turn joined on either side to the leading edge of the runners. The dredge blade is strengthened by three bracing bars joining the blade to the upper horizontal bar (Figure 1). In the centre of the two transverse bars a longitudinal brace is fitted, which is raised 3 in. Placed over this, and extending to each side of the dredge, a sheet of 16 S.W.G. steel is fixed to form a diving plate, raised in the centre to form a dihedral angle (Figure 2). The tow is taken from slightly behind the leading edges of the runners on a sisal bridle of 1 1/2 in. circumference. A wire bridle of 3/8 in. diameter is shackled to eye-bolts in the tail end of the runners, and is long enough to lie slack when shackled at the other end to the eye of the sisal bridle when this is in the towing position (Figure 3).

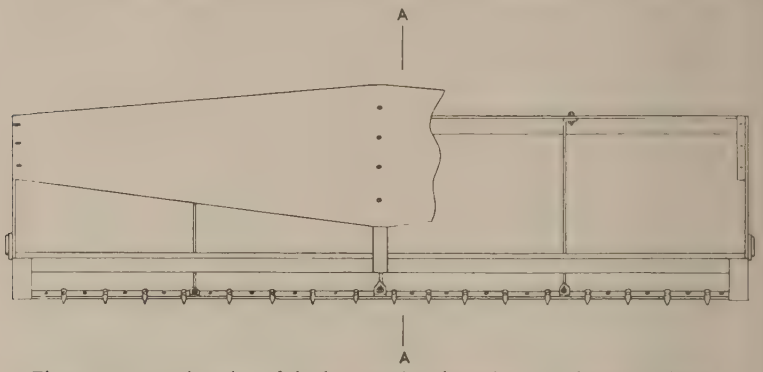

Figure 2. Front elevation of dredge. Section through A—A shown in Figure 3.

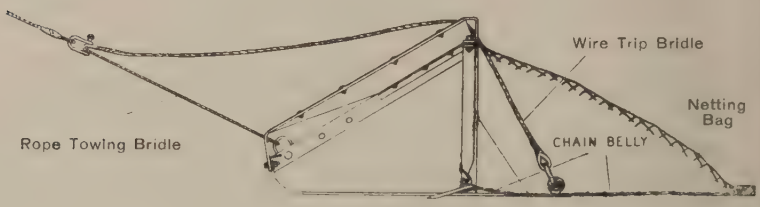

Figure 3. Section through A—A on front elevation, showing details of tow, trip bridle, and bag attachment.

The lower part of the bag is formed of iron rings in the normal manner and is attached in front to the trailing edge of the dredge blade, while the netting part of the bag is attached to the upper horizontal and the vertical members of the frame (Figure 3).

The fixed angle between the blade and teeth is maintained by their relationship to the runners. The tendency to lift is overcome by the shape of the dredge and the action of the diving plate, which tends to depress rather than elevate the dredge, allowing increased speed of tow and greater coverage of the ground. The dihedral angle on the diving plate gives hydrodynamic stability during shooting.

The sisal towing bridle will part if the strain on the tow becomes excessive, e. g., on fouling an obstruction, and the tow is then transferred to the tail of the dredge, thus allowing it to be rolled over and freed.

Minor incidental advantages are that the sledge dredge occupies less space on deck than one of the standard pattern for a given width of blade. The frame of the prototype costs £ 7, compared with £ 10 for a standard dredge. The new dredge is as easy to empty, by means of the cross-stick lifting bridle, as the standard dredge. Due to the controlled "bite" of the teeth, the sledge dredge requires less power for towing than the standard dredge.

At first a slight difficulty was experienced in shooting the new dredge, but if it was held clear of the hull of the boat, this difficulty was overcome, and in a very short time the crew became so expert that, on timed shots, no more time was taken shooting than with the standard dredge.

Although the dredge has been used for sampling on two cruises, opportunities for controlled comparative fishing trials against standard gear have been limited. The boat in use, due to the arrangement of the capstan, could tow only one dredge at a time. The following results, which represent hauls on grounds off the Orestone Rock, Torquay, on the main English Channel beds off Brighton, and in the Helford River, are based on 15-minute hauls; the dredges were used alternately, and fishing was carried out to a dahn buoy:—

Ground	Depth fathoms	Catch in 15-minute haul: Standard dredge	Catch in 15-minute haul: Sledge dredge	Ratio
English Channel, off Shoreham	19	18	41	1 : 2·27
	19	17	30	1 : 1·76
	19	10	55	1 : 5·5
	19	9	49	1 : 5·44
	19	13	61	1 : 4·69
	19	—	46	—
English Channel, further east	19	3	5	1 : 1·66
Off Orestone Rock, Torquay	9	14	47	1 : 3·35
	9	14	32	1 : 2·28
Helford River, Cornwall[1])	4	6	26	1 : 4·33
Mean catch per haul		11·6	39·2	1 : 3·38

[1]) Hauls of 10 minutes only.

A further series of hauls was made recently on inshore beds in Falmouth Bay. On these beds the sledge dredge caught only half as much as the standard dredge. A direct observation by diving was made on the working of the sledge dredge. It was observed that the bottom, which was of coral gravel (Lithothamnion), was formed into ridges about 6 to 9 inches in height with about 2 feet between crests, and the dredge, on runners, running parallel to the ridges, was skimming only their crests. A bottom of this type has not been encountered previously on escallop grounds around the British coast, as indicated by the relative performance of the dredges, nor has it been seen in the course of direct observations on the beds or in photographs of the bed of the sea in the Channel.

Acknowledgements.

I am grateful to the Irish Department of Fisheries, and to Dr. F. A. Gibson of that Department, for enabling observations to be made on the escallop beds at Castletownbere. I would also like to thank Mr. O. E. Griffiths of Bangor for help and advice on constructional details of the dredge.

Summary.

An escallop dredge with the blade held at the optimum angle in relation to the bottom by means of runners has shown an efficiency of the order of three times that of the standard escallop dredge on most grounds in tests carried out so far. A diving or depressor plate is fitted so that the speed of tow can be increased. A breaking line and a trip line are incorporated to reduce the risk of loss when the dredge fouls an object on the bottom.

Observations on the Sex Ratio and Mortality Rates in the Lobster (*Homarus vulgaris* Edw.).

By

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Introduction.

The Report on Lobsters (Anon., 1926) draws attention to variability in sex-ratios as revealed by both English and Scottish investigations. In the case of the American lobster, Herrick (1896) also reports on the sex ratio and draws attention to some anomalies. It has been suggested (Thomas, 1951) that the percentage of berried females might, in certain circumstances, afford a means of estimating the annual mortality rate.

In view of the reported discrepancies in the sex ratio of lobsters, and the importance of this aspect in relation to the regulations increasing the minimum legal landing size from 8 to 9 inches and protecting the berried female, introduced in Great Britain in May 1951, the present investigation, into the effects of varying mortality rates upon the sex ratio, was undertaken at the Marine Laboratory, Aberdeen.

Material and Methods.

Wilder (1952), discussing the results of extensive marking experiments, concludes that a proportion of lobsters (*Homarus americanus*) of between 8 and 10 inches in length moult twice in the year. In the case of larger male lobsters, moulting is annual, whilst in the case of a mature female moulting occurs only every other year, in alternation with the berried condition, which lasts from 10 to 11 months (Herrick, 1896). Wilder (1952) has shown that the American lobster, in the commercial range, increases in length at moulting by about 12 to 15 %. In the case of *Homarus vulgaris*, as with *Homarus americanus*, maturity occurs at around 11 inches, although in some instances a female lobster may mature at 10 inches. These findings broadly confirm those of previous workers.

A theoretical model has been drawn up of a lobster stock based on these data; a uniform recruitment has been assumed and a fifty-fifty sex

ratio up to 11 inches. The length at maturity is assumed to be 11 inches, and the percentage increase at casting 14 % by length. The mature male lobster is assumed to moult annually, irrespective of its length, whilst the mature female moults every other year only, being in a berried condition for the second year after moulting. Stock compositions have been worked out on this basis, with the assumption of a 70 % and a 30 % overall annual mortality rate respectively.

During the years 1934 to 1938, inclusive, commercial fishermen in Burnmouth (Berwickshire) and Rousay (Orkney), respectively, were commissioned to measure throughout the season a sample of about 2,000 lobsters and to record the overall length measurements, to the nearest quarter of an inch, from the tip of the rostrum to the end of the telson with the abdomen fully extended. The sample was classified into males, berried females, and non-berried females. Certain aspects of these data have already been reported and discussed (Thomas, 1951). In the present investigation the totals for each month over the whole period of five years have been summed and the measurements used collectively in order to minimize the effect of annual differences in recruitment and mortality rates. These data have been compared with the theoretical model referred to above.

Model Lobster Stocks.

Figure 1 shows the length frequency distribution for lobsters of 10 inches and over on the basis of a uniform 70 % annual mortality operating equally in respect of all classes and sizes of lobsters, with an assumed uniform annual recruitment of 100 males and 100 non-berried females at the maturity size of 11 inches. At lengths below maturity the stock composition is, by assumption, 50 % males and 50 % non-berried females. With the onset of maturity the growth-rate of the female is halved as compared with that of the male. Therefore the mortality in mature females, of a given size-group, between one moult and the subsequent moult two years later (i.e., to the next size-group) will be 91 % as opposed to the uniform 70 % in the case of the male, which moults annually. In consequence, the ratio of non-berried and berried females to males in successive size-groups subsequent to maturity falls off progressively (Table 1). On the other hand, since recruitment to the stock of mature female lobsters is maintained at the same level as the male (an assumed recruitment of 100 per annum at 11 inches), the stock of non-berried female lobsters in any given size-group subsequent to maturity will be augmented by 30 % in respect of berried females, being the survivors from the previous year's recruitment as non-berried females. The stock of female lobsters of all classes at 11 inches will therefore exceed the population of males by 30 % but will thereafter fall away at the rate of 91 %, as between one length-group and the next 14 % larger. The results of the effective difference in growth-rate between males and females on the ratio of non-berried and berried females, and of females of all classes to 100 males, are shown in Table 1.

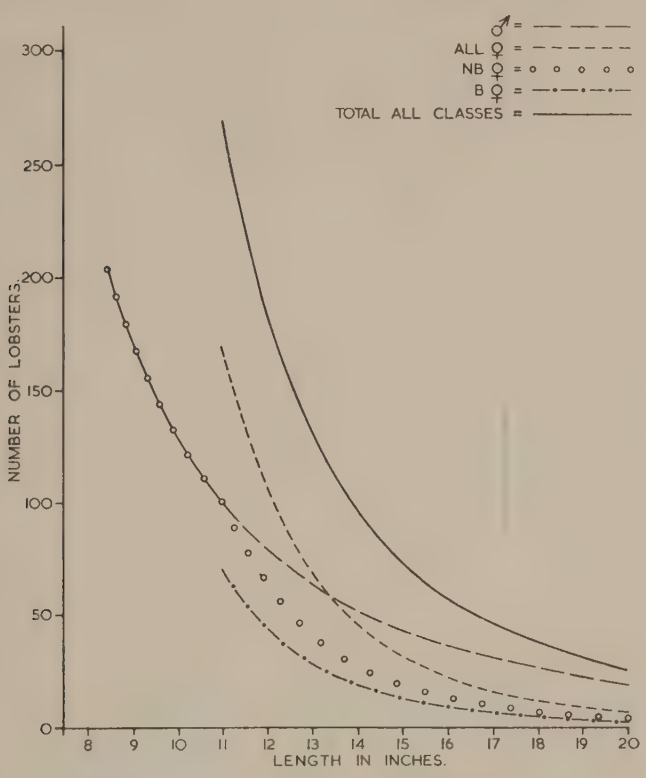

Figure 1. The overall composition of the larger lobsters in a model stock, based on a uniform recruitment of 100 males + 100 non-berried females at the maturity size of 11 inches and a 70 % mortality rate.

Table 1.

The number of non-berried, berried, and total female lobsters per 100 males in one-inch length-groups at annual mortalities of 70 % and 30 %, respectively, based on a theoretical stock.

Annual mortality		9-10 inches	10-11 inches	11-12 inches	12-13 inches	13-14 inches	14-15 inches	15-16 inches
	Males	100	100	100	100	100	100	100
70 %	Non-berried females	100	100	66·4	31·1	15·1	7·6	4·7
	Berried females	—	—	19·9	9·2	4·6	2·5	—
	Total females	100	100	86·3	40·3	19·7	10·1	4·7
30 %	Non-berried females	100	100	88·5	70·7	57·2	47·1	39·2
	Berried females	—	—	62·0	49·4	40·1	33·1	27·6
	Total females	100	100	150·6	120·1	97·2	80·3	66·9

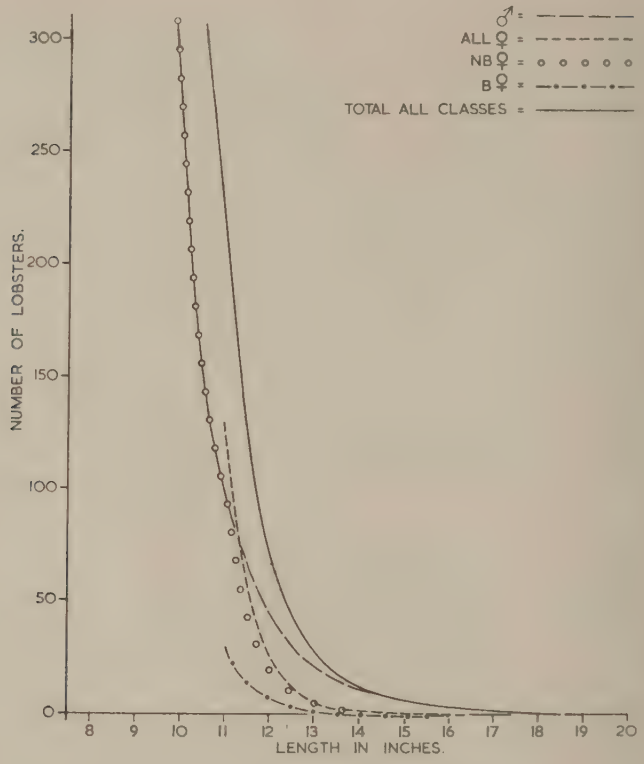

Figure 2. The overall composition of the larger lobsters in a model stock based on a uniform recruitment of 100 males + 100 non-berried females at the maturity size of 11 inches and a 30 % mortality rate.

Figure 2 gives the length frequency distribution for lobsters on the same basis as in Figure 1, except for an assumed annual mortality rate of 30 % only. The mortality in mature females of a given size-group and that of the next moulting size is, in this instance, 51 % as against 30 % in the case of males. The progressive falling off in the proportion of females to males subsequent to maturity is correspondingly less pronounced than in the case of the 70 % annual mortality rate (Table 1). The sex ratio in the various size-groups subsequent to maturity is, in fact, a function of the mortality rate.

In these models the onset of maturity has been assumed to occur at exactly 11 inches. Whilst this constitutes the approximate mean length at which the female lobster matures in Scottish waters, onset of maturity is commonly spread over the range 10 to 12 inches (see also p. 302). The precise length of first maturity assumed in the model

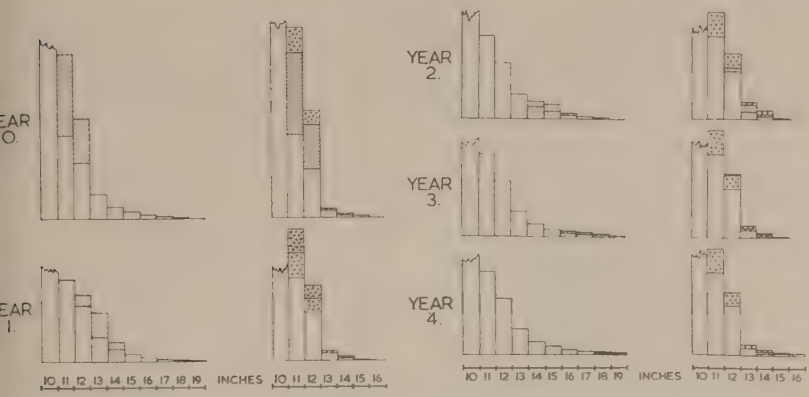

Figure 3. The composition of a model stock in which an otherwise uniform recruitment is subject to doubled recruitment to the stock of mature lobsters (11 inches to 12·54 inches) in year 0. The effect on the stock in the initial and four succeeding years is shown. The component representing the berried females is denoted by dots and that due to the increased recruitment by diagonal lines.

results in a sharp break in the stock composition at this point. In practice, the effects would be more gradual, but the result, in general, would not be markedly different.

The model has not been drawn up for length-groups under 10 inches; the proportion of these length-groups occurring in the stock, even on the assumption of a uniform mortality rate, will depend on the moulting frequency. In a given length-group, the more frequent the moulting the smaller will be the proportion which that length-group represents of the total stock. A uniform moulting frequency for either sex has been assumed over the whole size-range of the model. It seems likely that even after maturity the larger the lobster the less frequently will it tend to cast. This, however, may be expected to apply approximately equally to males and females, and over the relatively narrow range considered, the effects should not markedly influence the general results.

The above considerations are based throughout on a uniform level of recruitment. Large variations in recruitment to the marketable stock of lobsters will have a pronounced effect upon the sex ratio in particular length-groups after maturity. A marked deviation from the average level of recruitment would be expected to apply more or less equally to males and females and would not upset the ratios in length-groups below maturity, but thereafter, since the male casts twice as often as the female, marked disparities in the sex ratio of individual length-groups will result. Figure 3 shows the length composition in succeeding years of a theoretical lobster stock, based on a 70 % mortality rate, in which an otherwise uniform level of recruitment to the stock of mature lobsters is doubled in the first year. As, subsequently, the

Table 2.

The ratio of total females to 100 males, by lengths, in a model lobster stock during the years succeeding that prior to a double level of recruitment to the stock of mature-sized lobsters (11 inches).

It is assumed that the mortality is 70 % throughout and the recruitment other than the initial (× 2 in length-group 11-12.54 inches in year 0) is uniform.

Length-group inches	Year					
	—1	0	1	2	3	4
10	100	100	100	100	100	100
11	130·0	115·0	160·0	130·0	130·0	130·0
12	111·5	106·4	112·5	117·6	113·3	111·5
13	39·0	39·0	18·4	69·0	48·0	39·0
14	27·8	27·8	17·5	32·2	33·1	31·4

increased recruitment is reflected in succeeding length-groups, there is initially an increase in the proportion of males, this being followed at a later stage by an increase in the proportion of females, which afterwards decreases to the normal proportion as the return to uniform recruitment becomes dominant (Table 2).

Since the mature lobster is about 6 years old (W i l d e r, 1952), the length spread of any year-class, if this could be determined, would be wide, and in consequence, no very pronounced modification of sex ratio is to be expected between succeeding years, on this account. However, considerable differences in recruitment to the stock of marketable-sized lobsters may result from differences in natural mortality in the years immediately preceding attainment of marketable size. This could, for instance, be occasioned by variation in predation, such as by the octopus. Abnormally high recruitment to the stock of marketable-sized lobsters (at the new minimum) would also be occasioned at some time after an upward adjustment had been made to the minimum legal landing size, as was introduced in Scotland in 1951.

Sex Ratio at Burnmouth and Rousay, 1934 to 1938.

(a) Overall differences.

Figure 4 shows the percentage length composition aggregated over the years 1934 to 1938, inclusive, of the stock of lobsters of all classes at Burnmouth and Rousay, respectively, subdivided into males, berried females, and non-berried females. The data in respect of individual years have been combined in order, as far as possible, to smooth out annual variations in recruitment and mortality. In large measure this has been achieved in the case of Rousay, where the period was in any case marked by the relative uniformity from year to year. In the case of Burnmouth, however, the period was characterized by a fairly uniform and persistent tendency to increased exploitation and consequent decreasing size-composition of the stock (T h o m a s, 1951). In consequence, in the case of Burnmouth, the aggregated data will tend,

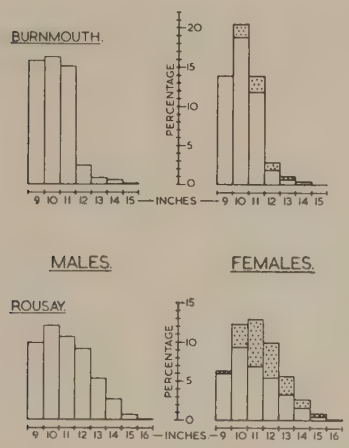

Figure 4. The composition of the lobster stocks at Burnmouth and Rousay, respectively, over the period 1934—1938 inclusive. Each length-group is expressed as a percentage of the total number of lobsters of length 9 inches and over. The component due to the berried females is denoted by dots.

in the lengths subsequent to maturity, to over-estimate the proportion of females to males, and of berried females to total females, as compared with a stock in which fishing mortality was uniform. The overall annual mortality at Burnmouth may be taken, roughly, as 70 %, as compared with about 30 % at Rousay (T h o m a s, 1955).

Table 3 shows the overall sex ratios in the two areas. As in the theoretical model, there is a marked increase in the proportion of females to males with the onset of maturity in the females, the change being particularly marked at Rousay, as may be expected in consequence of its lower mortality rate. It will be noted that whereas in the 9 to 10-inch group males predominate (in the theoretical model a fifty-fifty sex ratio was assumed in immature lengths), in the lowest length-group on which a significant proportion of females is berried (10—11 inches), total females exceed the number of males.

Table 3.

The ratio of non-berried, berried, and total female lobsters to 100 males in one-inch length-groups at Burnmouth and Rousay, respectively.

District		9-10 inches	10-11 inches	11-12 inches	12-13 inches	13-14 inches	14-15 inches
	Males	100	100	100	100	100	100
Burnmouth	Non-berried females	88·0	115·1	106·5	76·4	78·3	48·3
	Berried females	0·1	10·2	19·0	39·9	51·1	31·7
	Total females	88·1	125·3	125·5	116·3	129·4	80·0
Rousay	Non-berried females	61·2	79·1	65·8	60·1	62·8	62·6
	Berried females	2·2	24·9	57·2	49·4	44·4	40·6
	Total females	63·4	104·0	123·0	109·5	107·2	103·2

Table 4.

The percentage of berried females to non-berried females, by length-groups at Burnmouth and Rousay, respectively.

	9-10 inches	10-11 inches	11-12 inches	12 inches	13 inches	14 inches	15 inches
Burnmouth	0·1	8·8	17·8	52·2	65·3	65·5	—
Rousay	3·6	31·4	87·0	82·1	70·6	64·8	63·8

Table 4 shows that the earliest maturity size in a female at Rousay is less than 10 inches, whereas at Burnmouth the proportion of berried females in this length-group is negligible. It appears that first maturity in the females occurs at a lower size at Rousay than at Burnmouth. The difference is also shown in subsequent length-groups. The data suggest that at Rousay the majority of females attained first maturity at under 12 inches length, whereas at Burnmouth the corresponding figure is at least 13 inches.

In the theoretical model the proportion of females to males decreased from its peak level attained at the length of maturity (11 inches). The data in respect of Burnmouth and Rousay (Table 3) also show this trend. If, as assumed in the model, the female, having attained maturity, moults every second year and carries eggs in the intermediate years, the proportion of berried females to non-berried females in any length-group after maturity will be a measure of the mortality rate, providing recruitment is uniform. Where the mortality rate is uniform — for instance, at Rousay — the percentage of berried females to non-berried females (Table 4) should rise from the earliest maturity length to the level attained at the length at which all females are mature and be maintained at this figure throughout higher length-groups. In the case of Rousay, there is some falling off from the peak level attained in the 11 to 12-inch length-group. The most likely explanation for this is that the larger the lobster, the less frequently does moulting occur. It is reasonable to suppose that the period of incubation for the eggs is roughly the same, no matter what the size of the lobster. The proportion of the interval between one moult and the next during which the female would be in the berried condition would, in consequence, decrease with increasing length, with the result that a falling off would occur in the proportion of berried to non-berried females in the higher length-groups. On the other hand, as this decreased moulting frequency with increasing size would be expected to apply equally to males and females, the sex ratio of males to females of all classes would not thereby be affected.

(b) Seasonal variations.

Table 5 shows the monthly variation in the proportion of berried to non-berried females. The ratio in August is lower than at other times. When individual groups are considered, the August minimum is most pronounced in lobsters of length 10 to 11 inches, but is less so in larger lobsters, and is not apparent in lobsters of length 13 inches and over.

Table 5.

The percentage of berried females to total females of length 10 inches and over at Rousay, by months, averaged over the years 1934 to 1938.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
38·8	37·4	39·5	42·6	40·7	41·7	39·2	26·9	31·1	45·0	42·3	38·9

In the case of the American lobster, W i l d e r (1952) has shown that hatching occurs principally from mid-June to the end of August. H e r r i c k (1896) concluded that for the majority of American lobsters there is a definite spawning season, which is July to August, but that a minority, perhaps 20 to 25 %, spawn at other times. The main spawning and hatching seasons vary from one locality to another, as also does the period of incubation of the eggs. The low ratio of berried to non-berried females at Rousay in August probably reflects the interval when hatching has mainly finished and the peak of the spawning season has not been attained. If this is the correct explanation, it would appear that larger lobsters are less markedly seasonal in their habits of spawning and hatching than are the smaller ones. The Burnmouth data do not show the same seasonal characteristics as those for Rousay. It may be that such variations are obscured by the low proportion of berried females consequent upon the high mortality rate; in addition, the spawning and hatching season and the incubation period may well be different.

In their report on lobsters, the Interdepartmental Committee on Crabs and Lobsters (Anon., 1926) record the occurrence in Scottish waters of a seasonal variation in the sex ratio. Table 6 gives the percentage of males of length 10 inches and over in the total of all classes of lobsters, by months, at Burnmouth and Rousay, respectively. In the case of the latter creek, there appears to be a regular seasonal variation in which the ratio of males to females falls to a minimum in June, and reaches a maximum in September. This may well be attributable to a difference in the peaks of the casting seasons. The mature female lobster moults after the eggs have hatched, and this probably accounts for the relatively higher proportion of males taken in the catch during September. Similarly, it is possible that the lower proportion of males caught in June at Rousay is attributable to a seasonal peak frequency in the casting of males at this season. In respect of the variation in the proportion of males to females, as with the seasonal variation in the proportion of berried to non-berried females, the Burnmouth data are not as precise as are those from Rousay .

Table 6.

The percentage of males to total lobsters of all classes of length 10 inches and over, by months, at Burnmouth (B) and Rousay (R), respectively, averaged over the years 1934 to 1938.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
B	41·2	42·0	39·0	36·3	45·9	47·1	47·4	46·3	47·3	50·1	45·8	45·3
R	49·5	47·4	45·8	42·2	42·0	40·4	44·0	47·8	54·2	54·1	51·3	52·5

Discussion.

Consideration of the composition of the lobster stock as sampled by the creel is subject to the selectivity of this device. In the present paper no account has been taken of this factor. It seems probable that creels of the Scottish type in general use are decreasingly efficient in the capture of lobsters as the length exceeds 11 inches (T h o m a s, 1953). Apart from creel selectivity in respect of different lengths of lobster it may well be that, at any rate at upper and lower limits of the range of lobsters which can be taken by the creel, the various classes are not equally catchable. In comparisons of one area with another, differences in the fishing efficiencies of the creels employed in respect of various lengths and classes of lobsters between one area and another may be responsible for some apparent differences in stocks. On the other hand, as the length-range of practical significance is limited, none of these factors is likely to invalidate the present observations.

In the crustacea, where no means has yet been established for determining the exact age of an individual, extensive tagging experiments are necessary in order to determine the mortality rate. Providing the characteristics in respect of growth can be established — these appear in the case of the American lobster to be relatively constant in any one area — examination of sex ratios in certain length-groups may afford a means of approximate estimation of the mortality rate.

The variation in the sex ratio at maturity is not a characteristic of the lobster alone. It seems possible that the effect of decrease in growth-rate with maturity in the female may be a characteristic of other crustacea. In *Nephrops norvegicus,* for example, this factor may well account for the observed stock characteristics without the necessity of postulating any selective migration or behaviour difference (T h o m a s, 1954). Examination of sex ratio may also be of wider application in the determination of approximate mortality rates.

Summary.

The stock compositions, in theoretical models based on 70 % and 30 % mortality rates, respectively, are given.

The theoretical effects on the sex ratio of decreased moulting frequency in the mature female as compared with the male are shown.

The results obtained in the theoretical models are compared with observed data from two areas of different mortality rates.

Seasonal variation in the sex ratio is described.

Attention is drawn to the possible application of a study of the sex ratios in relation to mortality rates in other crustacea.

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Essay Review.

Recent Work on the Measurement of Salinity by Electrical Means.

By

Roland A. Cox.

The following papers are covered in the review:—

1) **A. W. Jacobsen.** "An instrument for recording continuously the salinity, temperature and depth of sea water." Trans. American Inst. Elec. Eng., **67**, pp. 1—9, 1948.

W. L. Ford. "The field use of an S. T. D. recorder." Sears Found., Journ. Mar. Res., **8**, pp. 84—96, 1949.

A. R. Miller. "A suggestion for the correlation of salinity data obtained with the S. T. D. recorder." Woods Hole Ocean. Inst. Techn. Rep. No. 54/17, March 1954.

2) **R. R. Dorrestein.** "Een registrerende electrische Zoutgehalte- en Temperatuurmeter voor Gebruik op Zee." Kon. Nederlands Meteor. Inst., Medd. en Verhand., 59, pp. 387—403, 1954.

3) **C. F. McCourt.** "An instrument for the measurement of the density of aqueous ionic solutions." Journ. Sci. Instruments, **30**, pp. 241—3, 1953.

4) **K. E. Harwell.** "Radio frequency salinity instrument model E." Agric. and Mech. College of Texas, A. & M. Research Found. Project 48, Techn. Rep., 4, 37 pp., 22 figs., March 1954.

K. E. Harwell. "Wien bridge and twin-T salinity instruments." *Ibid.*, Techn. Rep., 5, 41 pp., 18 figs., March 1954.

The following are of less general interest and are not reviewed in detail:—

J. H. Lincoln, R. G. Paquette, and **M. Rattray.** "Microsalinometer for oceanographic model studies." Univ. of Washington, Dept. Oceanogr., Techn. Rep., 26, ref. 54/10, 15 pp., 6 figs., March 1954.

Sauvage de Saint-Marc et J. Boudan. "Mesure de salinité." La Houille Blanche, **6**, p. 263, 1951.

It has been known for many years that the salinity of sea water can be determined with considerable accuracy from its temperature and electrical conductivity, and a number of instruments have been described, working on this principle to give continuous measurements. To be of the maximum service

such an instrument must be capable of operating from a ship at sea, and give instantaneous readings of salinity (to an accuracy comparable with that attained by titration) at any desired depth. No instrument has yet been described which fulfils these requirements, but the papers covered in this review each contribute useful features, and have given satisfactory results within their limitations.

In the "S. T. D." recorder, first described by Jacobsen, the sea water flows through a vinyl plastic tube fitted with three tubular bright platinum electrodes. The two electrodes at the ends of the tube are connected to earth, and the resistance of the sea water is measured between these and the third central electrode. Alternating current at 60 c./s. is used, and resistance is measured by a servo-operated bridge. Temperature is measured by a nickel resistance thermometer, and an electric servo-computer calculates the salinity. Salinity, temperature, and depth are recorded simultaneously. Limitations are the low accuracy of the salinity measurement, $\pm$ 0·3 ‰, the inconvenience of the 9-core cable necessary to connect the measuring section to the computer, which seriously limits the practicable depth range, and the complication and cost of the computing machinery. Results seem to have been fair in waters where large salinity changes occur, but the instrument is in any case not accurate enough for ocean work, and as Miller points out in detail, quite serious errors can be introduced when large temperature changes occur which are not accompanied by salinity changes.

The instrument described by Dorrestein is in many ways similar to the "S. T. D." recorder. The most important change is the replacement of the nickel thermometer by a thermistor element. Certain types of thermistor have temperature/resistance relationships very similar to those of sea water, and Dorrestein has used this property to construct a balanced bridge circuit in which temperature changes in the water are automatically compensated by a thermistor in the opposite arm. He accordingly attains a greater accuracy ($\pm$ 0·1 ‰) with a very much simpler and cheaper apparatus. Only three cores are needed in the cable to the undersea unit, which would simplify use at considerable depths, although the effect of temperature on the lead resistances would need attention, these being part of the bridge network. A servo-operated potentiometer keeps the bridge in balance and simultaneously records salinity on a paper roll. Dorrestein's paper includes a mathematical analysis of the relationships between temperature, salinity, and conductivity, showing how the errors due to inadequate temperature compensation can be minimized. The platinum electrodes of the "S. T. D." recorder are replaced by gas-carbon, which is claimed to give better performance as well as being cheaper. The frequency is 50 c./s. The mechanical construction is described in some detail, and it should not be difficult for a competent mechanic to build a similar instrument. Results have been good within the limitations of depth and accuracy, but in common with the "S. T. D." recorder some difficulty has been experienced owing to fouling of the electrodes, which causes calibration drift. In this connexion it is surprising that both instruments have been designed to operate at such low frequency, as it is an established principle of conductivity measurements that accuracy is increased by working at relatively high frequency, especially with solutions so concentrated as sea water. Another possible source of error not apparently considered by either Dorrestein or Jacobsen is the effect of pressure on the calibration of the salinity unit. Apart from the actual compression of the sea water at increasing depth there is a real possibility of deformation of the plastic tube carrying the electrodes, which would of course affect the conductivity

measurements. It is too early yet to assess the reliability of Dorrestein's meter, but it is certainly a great advance on any continuous-recording instrument previously described.

In contrast to the two low-frequency instruments, papers have recently been published independently by two workers describing instruments which use radio-frequency currents to measure conductivity. This technique uses a glass tube to contain the water with the electrodes outside the walls. The metal electrode and the water separated by the glass walls form a capacitor, and a tube with two such electrodes behaves as a resistance (dependent on the water) in series with a fixed capacitance. This makes it possible, by working at a high enough frequency, to measure conductivity without the electrodes coming in contact with the water. The fouling problem is much reduced, and at the frequency used, of the order of 10 Mc./s., polarization can be neglected. The main difficulty in this method is to generate a steady radio-frequency supply and measure the current flowing with sufficient accuracy.

The instrument described by McCourt was developed primarily for estimating the density of concentrated brine, but a modified version has been of some service in salinity measurements. The salinity cell serves as a damping resistor across a 12-Mc./s. oscillator, and by adjusting the various components the anode current of the oscillator valve is made approximately proportional to the conductivity of the water. Temperature changes are compensated by a copper resistance thermometer, and in favourable conditions salinity can be measured to $\pm$ 0·1 ‰. The principles used in both the electronics and the temperature compensation are not, however, sound for high accuracy or long-term stability, and it is doubtful if the instrument in its present form would be very useful for marine work.

The recent work reported by Harwell is much more advanced. The first report describes a practical instrument designed to record electrical conductivity and temperature simultaneously from a stream of water pumped through the instrument, or from samples poured in successively. These properties are measured accurately enough for salinity to be computed at any point to $\pm$ 0·1 ‰. In principle the apparatus consists of a glass tube with two external electrodes, between which a R.F. potential of about 5 V. at 7·5 Mc./s. is maintained at a steady value by comparison, after rectification, with a standard cell. The current flowing through the water is rectified and measured with a servo-potentiometer. The limiting factor is the stability of the electronic components and the germanium diode rectifiers, and to assist this all the components are kept in a thermally insulated box at constant temperature. No practical results are given, and the paper gives the impression that the instrument is more an experiment to determine the ultimate accuracy attainable by this arrangement than a working salinometer. The author seems to have concluded that this type of circuit is unlikely to give sufficient stability to be usable for routine measurements.

The second report by Harwell describes two alternative arrangements to improve stability. The first of these, the Wien bridge, is a circuit in which the frequency of an oscillator can be controlled by a resistance. In his experimental circuit this resistance is supplied by the sea water, and the frequency of the oscillator is thus dependent on the conductivity. In theory this would be an admirable arrangement for an underwater unit, as frequency can be measured easily and accurately and a frequency signal can much more easily be communicated through a long cable than a potential or a current. In order to keep up the performance of the amplifier circuit it was found necessary to keep the frequency down to about 2 Mc./s., at which frequency

the design of a glass conductivity tube with the necessary combination of resistance and capacitance was impracticable; serious difficulties were also found in maintaining stability, as the frequency was dependent on various factors difficult to control. The use of frequency-modulation methods, however, certainly merits further investigation, and may well be the best solution to the problem of continuous records at considerable depths.

The second experimental meter was a twin-T radio-frequency bridge operating at 10 Mc./s. The twin-T is a standard form of bridge in which a variable resistance in one arm is balanced by a variable capacitance in the other. With this frequency a glass cell with external electrodes is quite practicable. A bench-type meter has been built which measures conductivity to an accuracy corresponding to $\pm$ 0·005 ‰ in salinity. Combined with a thermometer of corresponding accuracy it gives an instrument for sample analysis almost certainly more accurate than chemical methods, and very much faster. It could probably be modified with a servo-balance to give a continuous record, and could be used with a pump for following variations in surface salinity, but for direct recording at any depth the bridge and servo-amplifier at least would need to be in the sea unit, and the difficulties involved seem prohibitive. The author considers that for the accuracy of which this circuit is capable it is impracticable to attempt a direct salinity reading, as the relationship between salinity, temperature, and conductivity is too complex.

To sum up, we now have in Dorrestein's meter an instrument which should give continuous readings of adequate accuracy for coastal and estuary surveys. We have in the twin-T meter the basis for an accurate bench meter. What is still lacking is the far more difficult direct-reading meter for ocean work. This will almost certainly involve an underwater electronic assembly conveying the necessary information to the recorder at the surface as a variable frequency signal.

Reviews.

H. W. Graham, J. M. Amison, and K. T. Marvin. "Phosphorus content of waters along the west coast of Florida." U. S. Dept. Interior, Fish and Wildlife Service, Spec. Sci. Rep. Fish., 122, 43 pp., 7 figs. Washington, D. C., 1954.

Dissolved inorganic phosphate, and dissolved organic phosphate plus that present in microplankton, were estimated monthly over fifteen months at a series of stations extending from river mouths to the 100-fathom line, 120 miles off-shore in the Caribbean.

The higher phosphate concentrations found near shore, in part due to inorganic phosphate in suspended particles, decreased rapidly on passing seaward.

High phosphate concentrations, with little organic phosphorus, were found in deep water below about 100 metres. From the sectional diagrams it appears that the base of the euphotic layer is usually well supplied with phosphate.

In the upper water layer, beyond 14 miles from shore, dissolved inorganic phosphate was rarely absent, quantities up to 0·1 *µg.*-ats. per litre being usually present, with somewhat larger quantities of organic phosphorus. Compared with temperate seas, the quantities of organic phosphorus in the warm upper layers of the Caribbean are low, due perhaps to more rapid dephosphorulation.

The integral mean concentration of total phosphorus in the water column at each station varied widely from month to month, suggesting complex movement of the water masses.

H. W. H.

H. Kay. "Eine Mikromethode zur chemischen Bestimmung des organisch gebundenen Kohlenstoffs im Meerwasser". Kieler Meeresforsch., **10**, 1, S. 26—36, Abb. 7. Kiel, 1954.

Estimations of the carbon in the organic matter in sea waters from the North Atlantic were made by K r o g h and K e y s in 1934, who found from 1 to 2 mg. C per litre. The difficult technique was greatly simplified by D a t z k o (*Doklady*, 1951, **77**, 1059) who quotes numerous analyses of Black Sea waters, which mostly contained slightly more than 2 mg. organic C per litre.

The micromethod described by K a y appears to be a definitive advance upon D a t z k o's technique in several respects; relatively complicated glass apparatus is used, largely in order to deal with a series of samples rapidly, with maximum accuracy, and in an entirely closed system.

In principle, 5—10 ml. of sea water, from which carbon dioxide present

as bicarbonates and carbonates has been removed, is heated with an equal volume of sulphuric acid containing silver chromate. The oxidation products are carried in a stream of oxygen through potassium iodide solution (in order to remove chlorine), through powdered antimony (in order to remove any iodine set free), over hot platinum gauze and silver wool (in order to complete oxidation of carbon monoxide and to complete absorption of sulphur oxides and halogens) before absorption in barium hydroxide. The carbon dioxide is estimated by titration.

The sensitivity of the method is discussed.

Estimations by this technique of organic matter, in solution after membrane filtration, in ocean waters should prove most interesting.

H. W. H.

F. C. Fuglister. "Average temperature and salinity at a depth of 200 metres in the North Atlantic." Tellus, **6**, 1, pp. 46—58, 3 figs., 8 charts. Stockholm, 1954.

Durch die Einführung der neuen Registriermethoden (Bathythermograph, Salinograph, Echograph, geomagnetischer Elektrokinetograph) in Verbindung mit den neuen funktechnischen Methoden der Positionsbestimmung ergibt sich für die Ozeanographie bei der Konstruktion von Übersichtskarten der regionalen Verteilung der betreffenden Faktoren in dem obersten Stockwerk bzw. am Boden der Ozeane eine ganz neue Problematik. Solange der Bearbeiter auf mehr oder minder punktweise Messungen der gesuchten Grössen (Temperatur, Salzgehalt, Meerestiefe, usw.) an relativ weitabständigen, jedoch noch ziemlich gleichmässig verteilten Stationen angewiesen ist, hat er bei der Konstruktion von Isolinien nur *eine* Schwierigkeit zu meistern, die natürlich mit wachsender Weitmaschigkeit der Messpunkte wächst: nämlich aus den verschiedenen Möglichkeiten der Konstruktion jeweils die geophysikalisch sinnvollste auszuwählen, um zu einem *plausiblen einheitlichen Bild* der regionalen Verteilung zu gelangen. Durch die gewaltige linienhafte Häufung der Beobachtungen längs vereinzelter Profile bei Einsatz der genannten Registriermethoden wird heute die Gewinnung solcher einheitlicher und geophysikalisch plausibler Übersichtskarten jedoch wesentlich problematischer, ja die Lage erscheint hier z. T. zunächst hoffnungslos. Stommel hat 1949 im *Journal of Marine Research* diese neue Problematik in Bezug auf die ozeanische Strömungsforschung klar herausgestellt, und allgemein bekannt sind ja die Schwierigkeiten, die sich bei der Konstruktion von in sich homogenen Übersichtskarten der Tiefenverhältnisse der Ozeane durch die ungeheure Verdichtung der Messpunkte in den Echogrammen ergeben.

In der vorliegenden Studie hat nunmehr Fuglister mit grosser Sorgfalt und Objektivität die Fragen geprüft, inwieweit seine neuen auf rund 40,000 bzw. 14,000 Messpunkten und hierbei z. T. auf fast synoptischen Registrierungen beruhenden Übersichtskarten von Temperatur und Salzgehalt für 200 m. Tiefe im Nordatlantischen Ozean als repräsentativ gelten können und ob die entsprechenden auf wesentlich spärlicheren, aber gleichmässiger verteilten Beobachtungen des "Meteor"-Atlas (Bd. VI) als "überholt" ("obsolete") anzusehen sind oder nicht. Wie ungleichmässig das etwa 10 bzw. 4 mal so grosse Beobachtungsmaterial in Fuglisters Karten von t° bzw. S‰ verteilt ist, lehrt seine statistische Übersichtskarte nach 1°-Feldern, aus der hervorgeht, dass im Nordatlantischen noch eine Fülle von 1°-Feldern ohne jede Messung in 200 m. Tiefe existiert, dass aber daneben besonders im Bereich des Golfstroms quasisynoptische engabständige Aufnahmen mit vielen Messpunkten pro 1°-Feld vorliegen. Die *Temperatur- und Salzgehalts-Übersichtskarten* Fuglisters,

in denen bei der Konstruktion der Isothermen bzw. Isohalinen jede Ausgleichung vermieden ist, stellen also in Wahrheit *eine Art Kombination von mittleren Zuständen und mehr synoptischen Augenblicksbildern* dar. Der Vergleich mit den entsprechenden 200 m.-Karten des "Meteor"-Atlas lehrt bei genauerem Studium, dass in allen wesentlichen Zügen eine bemerkenswert geringe Differenz zwischen den beiden Sätzen der Karten besteht, wenn man von den grösseren Unregelmässigkeiten des Kurvenverlaufs im einzelnen innerhalb der neuen Karten zunächst absieht. Hieraus folgt eine zweite bemerkenswerte Tatsache, dass nämlich in ausgedehnten Gebieten des Nordatlantischen Ozeans im 200 m. Tiefe die Jahreswelle der beiden Faktoren sehr gering, ja in den niederen und mittleren Breiten kaum feststellbar ist. Ferner zeigt sich, dass alle überwiegenden Windtriften wie die Äquatorialströmungen in 200 m. praktisch erloschen sind und dass sich die Kernmassen der grossen Stromsysteme, die zumeist durch ein intermediäres Salzgehaltsmaximum gekennzeichnet sind, im Durchschnitt in Tiefen um 200 m. unterhalb der Meeresoberfläche ausbreiten. Gerade in letzteren, d. h. in den grossen und tiefreichenden Strömungen wie dem Golfstromsystem weisen Fuglisters neue Übersichtskarten z. T. aus den genannten messtechnischen Gründen, z. T. aber auch aus dynamischen Gründen eine Fülle interessanter Details auf, die in den "Meteor"-Karten nur schwach angedeutet sind oder vielfach ganz fehlen, wie z. B. der Zerfall des Golfstromes in mehrere, teilweise von schwachen Gegenströmen getrennte Äste (multiple currents) — eine Erscheinung, die in den "Meteor"-Karten nur östlich der Neufundlandbank schwach erkennbar ist. Hierdurch sind die stärkeren horizontalen Gradienten von t° und S ‰, die ja mit den schmalen Bändern der starken Konvektionsströmungen im Golfstromsystem zusammenfallen, in Fuglisters Karten in mehrere schmalere Streifen aufgespalten. Wenngleich in 200 m. Tiefe die periodischen Schwankungen der ozeanographischen Faktoren, also die Jahreswelle, zumeist praktisch bedeutungslos sind, gilt dieses nicht für die unperiodischen Schwankungen von Tag zu Tag, Woche zu Woche, Jahr zu Jahr. Je enger das Beobachtungsnetz ist, je mehr quasisynoptische Registrierungen vorliegen, umsomehr müssen naturgemäss solche unperiodischen Änderungen von t° und S ‰ und Verlagerungen der Stromstriche zur Wirkung gelangen und die Temperatur- und Salzgehaltsfelder komplizierter gestalten. Fuglister hält es für möglich, dass sich in Zukunft bei gleichmässigerer Verdichtung der Messpunkte und bei ausgeglichenerem Gewicht von 1°-Feld-Mittelwerten die Kompliziertheit der Isothermen- und Isohalinenbilder wieder mildern und sich mehr dem Stil der "Meteor"-Karten annähern werden. Hierfür spricht auch Fuglisters neue Karte der absoluten Temperatur-Schwankung, d. h. der Differenz zwischen den beobachteten höchsten und niedrigsten Temperaturen innerhalb der 1°-Felder. Sehr aufschlussreich ist ferner die Karte der Temperatur-Anomalien in 200 m. Tiefe, die Fuglister auf Grund von 1°-Feld-Mittel- und Zonenwerten entwirft und die er einem ähnlichen Versuch des Rezensenten (1936) gegenüberstellt und die naturgemäss infolge der Verdichtung des Beobachtungsmaterials — besonders im Bereich des Golfstromsystems — zahlreiche neue Details des Wärmeüberschusses und Wärmedefizits ergibt. Fuglister weist besonders auf den Unterschied zwischen beiden Darstellungen im Bereich der Island-Faröer-Shetland-Schwelle hin und betont, dass in seiner neuen Karte die Kontinuität des Warmwassertransportes im Golfstromsystem über dieser Schwelle weitgehend unterbrochen zu sein scheint. Nach Auffassung des Rezensenten spricht auch die neue Karte nicht gegen eine solche Kontinuität über dieses Schwellensystem hinaus, da hier die Isothermen und Isohalinen durch morphologische Beeinflussung etwas gehoben werden

und in einer 200 m.-Horizontalkarte Reduzierungen bzw. Unterbrechungen des Warmwassertransportes des Golfstromsystems vorgetäuscht werden. Eine volle Kontinuität des Warmwasser- und Salztransportes würde sich im Golfstromsystem dann ergeben, wenn man Karten mit den Isanomalen der Temperatur und des Salzgehalts für die auf- und absteigende Kernschicht entwürfe, welche letztere durch das zwischen etwa 50 und 300 m. Tiefe schwankende intermediäre Salzgehaltsmaximum gekennzeichnet ist. Eine solche Anwendung der Kernschichtmethode auf das Golfstromsystem erscheint dem Rezensenten als eine vielversprechende Aufgabe, wie sein entsprechender Versuch in der Berichten der "Altair"-Expedition (1940) lehrt.

In den Schlussfolgerungen gelangt Fuglister auf Grund der vergleichenden Betrachtung zu dem Ergebnis, dass für das Studium der grossen Meeresströmungen seine neuen 200 m.-Mittelkarten (von t° und S ‰) vorzuziehen sind, ganz abgesehen davon, dass sie — im Gegensatz zum "Meteor"-Atlas — auch alle Nebenmeere des Nordatlantischen Ozeans berücksichtigen. In Bezug auf den klimatologischen Mittelzustand behalten jedoch nach Auffassung Fuglisters die Karten des "Meteor"-Atlas ihren Wert, was er wie folgt formuliert: "It is quite apparent ... that, far from being obsolete, the charts in the 'Meteor' Atlas that deal with conditions at depths of 200 m. in the North Atlantic are still to be considered as accurate representations of the mean state. This atlas shows ... a certain continuity of conditions with increasing depth and, therefore, we may assume that all the charts in the atlas are equally reliable ... It may seem a paradox but the chief value of the new 200 m. average temperature chart ... is the fact that it does not represent a true average picture ... This is especially evident in the major current areas." Aber wir müssen nach manchen Anzeichen erwarten, dass auch in den grösseren Tiefen sich unperiodische Änderungen der Tiefenzirkulation fühlbar machen, so dass es sich empfiehlt, solche systematischen Aufnahmen der ozeanischen Schichtung wie sie im "Meteor"-Atlas enthalten sind, nach Jahren zu wiederholen. Die wertvolle Untersuchung Fuglisters ist nicht nur methodisch von grossem Interesse, sie wirft auch eine Reihe neuer Fragen und Probleme auf.

Georg Wüst.

K. F. Bowden. "Note on wind drift in a channel in the presence of tidal currents". Proc. Roy. Soc., A, **219**, pp. 426—446, 9 figs. London, 1953.

The title of this important theoretical paper indicates its subject fairly precisely, apart from the fact that not only the wind drift but also the slope of the sea surface is dealt with. Moreover, the paper is somewhat more than just a note; the results are applied to the English Channel.

The investigation follows Jeffreys's (1923) treatment of the bottom friction in assuming the existence of a skin-friction layer close to the bottom, the details of the velocity distribution inside that layer being disregarded. The frictional stress at the outer surface of the layer is taken to be proportional to u_0^2, where u_0 is the magnitude of the drift current there, and to be in the opposite direction to that current; u_0 is referred to as the "bottom current". An eddy viscosity is assumed which is constant with depth throughout the water above the bottom layer. The water is assumed to be homogeneous and lateral stresses are neglected. The motion, being restricted to a channel or narrow sea, is assumed to occur principally along the length of the channel, so that geostrophic effects are of the second order. The wind drift is supposed to occur as a perturbation of fairly strong tidal currents. The presence of such tidal currents, of course, makes the practical problem of measuring wind

drift more difficult than it would be without them, but it makes the theoretical problem dealt with in this paper simpler in two ways: (1) the assumption of an effective eddy-viscosity constant with time and depth is likely to be a better approximation; and (2) if the bottom friction is proportional to the square of the *total* velocity at the bottom, its non-periodic component, due to and acting on the drift current, is linearly proportional to the *drift* velocity u_0. Since the "inertia terms" of the acceleration (in the Eulerian form of the equations of motion) are assumed to be of relatively small importance, the equations of motion for the drift current become linear.

Consideration is chiefly given to the steady state. As a non-stationary instance the case of the flow in a uniform channel, with zero surface gradient along the channel and with a surface wind stress that has jumped from zero to a constant value, is considered in order to get an idea of the time required for the drift current to develop under the influence of the downward transfer, by eddy viscosity, of momentum which is supplied at the surface at a constant rate. The times required for the surface and the bottom currents to reach 90 % of their steady state values appear to be of the order of several hours up to a day or two, for depths of up to 100 m. and a tidal-current amplitude of 1 m./sec.

The following values of the numerical quantities which occur in the equations of motion and in the bottom boundary conditions have been taken as being the most probable:—

$$\frac{\text{bottom friction stress}}{\text{water density} \times u_0^2} = 2 \times 10^{-3};$$

$$\frac{\text{eddy viscosity}}{\text{depth} \times \text{tidal current amplitude}} = 2{\cdot}5 \times 10^{-3}.$$

Steady-state solutions of the equations of motion, satisfying the equation of continuity and the boundary conditions at the sea surface and the bottom, have been derived analytically and evaluated numerically for various cases, differing from each other either geometrically or dynamically.

Particular geometrical cases dealt with are the uniform channel and the uniformly convergent channel.

Dynamically, in order to reach a solution, the problem needs further specification by a side condition relating either to the surface elevation at the ends of the channel or to the drift transport through any section of the channel, the most simple cases being those of zero difference in surface level between the ends and of zero transport. The latter case applies to a channel with one end closed. In a uniform channel with uniform wind stress, the case of zero difference in surface level between the ends has zero surface gradient throughout the whole channel. The drift current has a linear vertical velocity distribution, the ratio of surface current to bottom current depending on the values of the hydrodynamical constants used. With the values mentioned above, this ratio becomes 2 : 1. It appears, furthermore, that the drift velocities are very markedly reduced by the presence of the tidal currents, particularly at the lower wind speeds. This reduction is due to the fact that the tidal currents cause increased bottom friction in the drift current. If the channel is not uniform, but converges say in the direction of the wind, and if the same level is assumed at both ends, a maximum of surface elevation is found somewhere nearer to the narrow end than to the wide one. The large magnitude of the computed surface drift current at the narrow end shows, however, that this case can have little to do with the English Channel.

The case most nearly corresponding to observed drift through the Straits

of Dover appears to be the one having zero surface gradient along the channel in the Straits. The computations have been extended to cover the case of a channel in which width and depth vary non-uniformly with distance along it, the cross-section area, the depth, and the tidal current amplitude being taken as known for a number of sections across the channel. This method was applied to the English Channel, fifteen sections being used. With a wind blowing towards the narrow end, the surface current is in the direction of the wind stress along the whole channel, but the bottom current is in the opposite direction over a distance of about 240 km. from the wide end.

According to the theory presented, the drift velocities in the steady state should be proportional to the surface wind stress and thus to the square of the wind speed, instead of to the wind speed, as has been inferred from comparative wind and current observations. The cause of this difference lies in the fact that Bowden has taken the eddy viscosity to be independent of the wind. At a certain wind speed it is possible, however, to make the theory agree with observations at the "Varne" lightvessel. A test of the theory would then require a determination of (a) the corresponding surface elevations along the English Channel or (b) the velocity profiles at other cross-sections.

It is not suggested that it would be practicable, in the present state of knowledge, to compute in detail the characteristics of the wind drift, given the dimensions of a channel and the wind velocity. The intention has been, rather, to indicate the general nature and order of magnitude of the effects to be expected. This information may be helpful in planning a programme of observations at sea, without which it seems unlikely that fundamental advances in the knowledge of wind drift can be made.

P. Groen.

L. A. Post. "A practical method for the prediction of the surface currents of the ocean." Tellus, **6**, 1, pp. 59—62, 3 figs. Stockholm, 1954.

Die Arbeit stellt einen methodisch bemerkenswerten Versuch dar, durch Berechnung des stationären Konvektionsstromes aus der dynamischen Topographie und dem Massenfeld und durch gleichzeitige Beobachtung der momentanen Oberflächenströmung (mittels des geomagnetischen Elektrokinetographen) und der lokalen Windverhältnisse zu einer Vorhersage der Oberflächenströmungen zu gelangen. Hierbei wird angenommen, dass die vektorielle Differenz zwischen gemessener und berechneter Strömung den Anteil darstellt, der winderzeugt ist. An einem 1950 mit dem U. S. C. G. C. "Evergreen" gewonnenen simultanen Beobachtungsmaterial wird versucht, die Brauchbarkeit der Methode zu demonstrieren. Ein ganz neuer Typus ozeanographischer Stromvermessung, der mit wenigstens 3 Forschungsschiffen an engabständigen Stationen (am besten Ankerstationen) zu gleichzeitigen und kontinuierlichen Bestimmungen des "dynamischen" Stroms, des "beobachteten" Stroms und der Windverhältnisse (Richtung, Geschwindigkeit, und Dauer) zu gelangen sucht, wird entwickelt. Inwieweit es möglich sein wird, auf diese Weise die berechneten Schichtmittelwerte des stationären (permanenten) Konvektionsstroms, die in Wahrheit Durchschnittswerte für einzelne Tiefenhorizonte der Stromgeschwindigkeitskomponenten senkrecht zum Schnitt zwischen 2 benachbarten Stationen darstellen, mit den beobachteten Punktwerten des momentanen Stromes mit Erfolg zu korrelieren und zu quantitativ brauchbaren Stromvorhersagen zu gelangen, kann nur die Erfahrung auf Grund von systematischeren Untersuchungen lehren.

G. Wüst.

K. Wyrtki. "Der grosse Salzeinbruch in die Ostsee im November und Dezember 1951". Kieler Meeresforsch., **10**, 3, S. 19—25, Abb. 6. Kiel, 1954.

The study described in this paper forms part of the author's comprehensive researches on the water exchange between the North Sea and the Baltic. The results presented in it, however, have their main interest as contributing to the knowledge of the considerable increase in salinity observed in the Baltic basin during the last two decades. The investigation is based on salinity, current, and sea-level observations in the Transition Area. Three different factors have been of decisive importance for the irruption of salt-rich water into the Baltic during the period in question. Strong and persistent westerly winds which prevailed for about three weeks were the primary cause of the phenomenon. Furthermore, the low sea-level in the Baltic at the start of the period provided favourable conditions for the penetration of large masses of water into this basin. Finally, the salinity in the deep layers of the Kattegat was unusually high. According to the author's calculations, the quantity of salt transported into the Baltic during the period and remaining there amounted to $2{\cdot}4 \times 10^9$ tons. This quantity of salt is sufficient to raise the salinity of the whole of the water in the basin by 0·1 ‰, on the average. The result is of considerable interest, because it allows the author to conclude that a few such occurrences would be sufficient to account for the gradual increase in salinity in the Baltic in recent years.

E. L.

K. Wyrtki. "Die Dynamik der Wasserbewegung im Fehmarnbelt II." Kieler Meeresforsch., **10**, 2, S. 162—181, Abb. 11. Kiel, 1954.

This paper is a continuation of an earlier research. In it the author has directed his attention mainly to the stratification of the water and its influence on the currents in the Fehmarnbelt region. From the examination of a very large number of actual situations, he demonstrates the considerable differences in the current conditions which prevail when the increase in salinity with increasing depth is fairly slight, and those which are observed during periods of marked stratification. In the former cases, which are relatively more frequent during winter time, the currents are, on the whole, uniform throughout the entire water column, the degree of uniformity depending mainly on the prevailing meteorological factors and the slope of the sea surface. In the latter cases, which are more usually observed in summer, it is, as may be expected, the surface current only that is a more or less distinct function of the factors mentioned above, whilst, as a rule, in-going currents characterize the conditions in the bottom layer. By way of numerical example, it may be mentioned that in cases with weak stratification ($\Delta S < 2$ ‰) not less than 89 % of the total number of observations showed the same current direction throughout the whole water column. On the other hand, the author gives 84 % as the frequency of occurrence of in-going currents in the bottom layers for all the cases when the stratification was relatively pronounced ($\Delta S > 2$ ‰). Another question studied by the author in this connexion is that of the oscillations in the sea basin caused by abrupt variations of wind and air pressure. His investigations give 38·5 hours as the period of oscillation in the Baltic—Gulf of Bothnia system, a value which agrees fairly closely with the time determined earlier by Neumann.

E. L.

P. S. B. Digby. "Plankton production in Scoresby Sound, East Greenland." Journ. Animal Ecol., **22**, 2, pp. 289—322, 3 figs., 4 pl. Cambridge, 1953.

The author spent one year at Scoresby Sound in East Greenland and during this period took quantitative vertical hauls with nets equipped with meters, for phytoplankton and zooplankton, usually through a hole in the ice. Observations on temperature and salinity were also made, and light transparency measurements were carried out by means of a Secchi disk.

As the plankton was at times very scarce, the catches were increased by letting the nets catch both during descent and ascent, one or more times according to the density of the plankton. One might think that there would be some loss of material when the net was turned near the bottom, but the author claims that there was no such loss.

The phytoplankton was determined mostly by measuring in Harvey pigment units the chlorophyll content dissolved out in acetone. Part of this was done on phytoplankton taken in net hauls and part on samples passed through membrane filters. Pigment values were less than 1 unit/m^3. throughout the winter. Production set in in May, and high values were found from June to August. The cell counts from net hauls indicated a succession of species beginning with *Nitchia, Navicula, Amphiprora,* and others, passing over to chaetocerids, peridinians, and tintinnids in July and August. This succession was the same as found by earlier workers but the author missed the initial production of flagellates indicated by other workers, because membrane samples were not taken at the beginning of the season.

The membrane samples were taken from a mixture of water samples from different depths in order to give figures for the total production of phytoplankton, but it would have been very useful to have had some samples taken separately from different depths, especially the surface layers.

The method of measuring the standing crop of phytoplankton by the chlorophyll content from net or membrane samples has been in use for a comparatively long time. It is easy to use and requires only a little time in comparison to the often very tiresome and tedious method of counting cells from sedimentation or net samples. But one has to be aware of the limitation of the method. The figures are highly relative, and part of the chlorophyll measured may not be active, deriving from the guts of plankton animals or from faecal pellets or plant detritus. When comparing the standing crops of phytoplankton in two areas so far apart as Scoresby Sound and the English Channel one has to take into consideration that temperature, salinity, depth of the productive layer, light conditions, and other factors are entirely different, and therefore the same amount of chlorophyll will undoubtedly not be equivalent in the two areas. The composition of species, in the two areas, as found by comparison of the pigment from membrane and net samples, was also different, as pointed out by the author.

It is to be regretted that no phosphate determinations were made.

The zooplankton was divided into different categories, the main one being the copepods, and the biomass was determined by sieving the samples through sieves of silk of different mesh size, and weighing them after removal of excess water by touching the underside of the silk with filter paper.

The biomass of the medium and large copepods decreased very much from September to a minimum in March and thereafter increased to an extended peak in July and August.

As the hauls were taken only as deep as 50 metres when the depth of the water was approximately 80 metres the sampling of zooplankton was

incomplete, since a number of plankton animals usually remain below that depth, especially in winter. The author also points out that the first sharp fall in biomass in September was the result of certain species of copepods sinking deep and in the same way an increase during midwinter, and especially at the beginning of April, was caused by an upward migration of the plankton animals. If the hauls had been taken right to the bottom, it would have been easier to find out whether any new plankton had been introduced from other localities.

An experiment was made on the oxygen consumption of copepods. When the low temperature is taken into consideration the results obtained are in conformity with those found in more temperate waters.

The author makes a number of deductions as to the metabolism and maintenance of the stock of copepods and comes to the conclusion that during the absence of phytoplankton the stock is maintained partly by feeding on organic matter, which may also include individuals of their own kind. This deduction is also applied to species which are known to be filter feeders. This might well be true, but one ought also to bear in mind that a great part of the food ingested the phytoplankton, for instance, is stored as fat, which may be used in the process of metabolism, when little or no food is available.

It appears that, with the reservations made, the author has carried out a noteworthy piece of work, of special value because it was done in an extremely arctic area, and covered the production cycle throughout a whole year.

K. F. Wiborg.

H. B. Moore, H. Owre, E. C. Jones, and T. Dow. "Plankton of the Florida Current. III. The control of the vertical distribution of zooplankton in the daytime by light and temperature." Bull. Mar. Sci. Gulf and Caribbean, **3**, 2, pp. 83—95, 1 fig. Miami, 1953.

The object of this short paper is to substantiate Moore's earlier hypothesis that while light may control diurnal vertical migration, temperature plays the major role in influencing the depth occupied by plankton during the daytime. From the data available, the point is effectively established.

A measure of the depth distribution of the plankton is made in the same manner as that adopted in the previous papers of this series. Each set of observations comprises six or seven oblique hauls at successive depths, taken during daylight and monitored by a depth/distance recorder. From each such series two parameters are computed. Firstly, the *mean day level* of the population, which is defined as the depth above, or below, which 50 % of the total catch was taken. Secondly, the *spread*, which is given by the distance between the depth above which 25 % and the depth above which 75 % of the population was taken. Four gross categories of animals are considered — the pteropods, siphonophores, chaetognaths, and copepods — and by lumping the four together a fifth category, termed "all species", is added.

These two values for each category of plankton, the *mean day level* and the *spread*, are then collated with the contemporary depths of the 15°C. isotherm and the 10^{-2} isolume. To facilitate the statistics, the correlations and regressions are computed in each case from the divergence of the various observations from their annual means.

The argument is developed by a series of statistics:—

(a) The variations in *mean day level* are compared with the deviations in depth of the 15°C. isotherm. With the exception of the copepods all categories show correlations significant at the 5 % level. The copepods

are brought into line by demonstrating a seasonal variation in their depth distribution and then correcting for it.

Similar tests between *mean day level* and the 10^{-2} isolume fail to reveal any relationship between the two.

(b) It is deduced from a series of partial regression coefficients that the depth occupied by the upper 25 % of the plankton of the various categories is more closely related to the depth of the isolume while that of the deepest 25 % of the plankton is influenced rather by the depth of the isotherm.

(c) The suggestion inherent in (b) is that the upper limits of the *spread* are conditioned by light and its lower limits by temperature. To test this point, deviations from the average distance between the 15°C. isotherm and 10^{-2} isolume are correlated with the deviations from the mean annual *spread*. Again the results are highly significant, all giving values of $P < 1$ %.

(d) The changes in depth which are considered to be due to variations in light and temperature are eliminated and it is then shown that in three of the four plankton categories that can be tested, there is a positive correlation between *spread* and *mean day level*.

We are left then with three conclusions, all of them extremely rational but nevertheless of fundamental importance, if generally applicable. Firstly, vertical distribution of the plankton is conditioned by the depth of some optimum temperature during daytime. Secondly, organisms nearer the surface are under control of light whereas those in the deeper layers, farther removed from the source of light, are more influenced by temperature. Thirdly, the deeper the habitat of the animal, the less restricted is its vertical spread.

While one cannot fail to admire the authors' concise and lucid exposition, there remains the feeling that such important work warrants a more detailed account. The reader is given nothing but the completed statistics and the authors' interpretation of them and so may find himself with many unanswered questions. For example, the number of observations involved can only be deduced approximately from the fiducial limits used in the tables. The distribution of the observations in time is not stated. The three parameters used, the depths above which 25 %, 50 %, and 75 % of the population were caught, give only a partial picture of the disposition of the plankton with depth; the reader can only speculate as to whether the animals involved were spread more or less evenly over their depth range or were aggregated near their *mean day level*. No actual depths, or numbers of animals found, are given. It is to be hoped that as this excellent work proceeds, more details of the raw data will be made available so that a better appreciation of its implications can be made.

K. M. R.

K. F. Wiborg. "Investigations on zooplankton in coastal and offshore waters of western and north-western Norway with special reference to the copepods." Fiskeridirek. Skr., Ser. Havunders., **11**, 1, pp. 1—246, 102 figs. Bergen, 1954.

Wiborg's report provides a most comprehensive account of the plankton in Norwegian waters; it is packed with new and relevant detail. The majority of his observations come from divided vertical hauls taken at four fixed stations off the west coast of Norway — two to the south at about 61°N. and 63°N., and two further north at about 68°N.; one of these is seaward of the Lofoten Islands and the other inside the Vestfjord. Samples

were taken frequently, on the average approximately once a fortnight, from October 1948 until December 1951. Recourse is also taken to data from earlier and contemporary cruises and to the regular collections from Weather Station M at 66°N., 2°E.

The "General part" of the report, some 50 pages, deals with the plankton as a whole — the variation in time of the standing crop of zooplankton expressed both in terms of volume and of animals present. At the more southerly stations maxima occur in April and again in June July, whereas at the northern ones the periods of highest crop are a month or so later. These dates can be compared with the single maximum found farther off shore in June at Station M. In the main, more plankton was found in the north than in the south, but there was at all stations a noticeable increase in the crop from 1949 to 1951. Although larvae of benthic forms were at times abundant in the spring and summer and medusae and salps might swell the volume during the autumn, the copepods were the main constituent of the plankton both numerically and by bulk. *Calanus finmarchicus* was by far the most important species.

Various groups of animals are categorized by their habitat and origin and most interest here attaches to the *Allochtonus* species as indicators of Atlantic influence in the coastal waters during the autumn: they appear in the southern catches about a month earlier than the northern ones. However, W i b o r g demonstrates most forcibly that it is not only the exotic forms which can provide evidence of extraneous water; the ubiquitous *Calanus* can equally be used. In common with many other workers, he finds significant variations in the modal size of *Calanus* populations taken in different catches. It has been usual in the past to attribute such differences to the varying growth-rate of subsequent generations, the seasonal differences in water temperature and in availability of food, etc. But W i b o r g has an interesting series of measurements made on samples all taken within the period of a week at various points from Ona in the south to Bear Island. It is quite easy from these to differentiate between the smaller sized local stocks and the larger forms associated with arctic water and it is most revealing to learn how close together quite different stocks can exist just south of Bear Island. Again, he shows how the smallest forms of *Calanus* in the coastal stations are taken during the autumn and so may have originated in warmer waters together with the salps and other "indicators" of Atlantic influence which are found near the Norwegian coast at the same time.

The second and longer part of the report deals with the biology of the various plankton species, particularly the copepods. Detail varies, but for most species we are given the seasonal variation in numbers and the distribution with depth. Most catches are broken down into age compositions, to give breeding periods, and into size-frequency distributions.

It is impossible in a short review to do justice to the wealth of information provided. Indeed, there are so many facts that the paper is not easily absorbed at first or even second reading. However, it is set out in an orderly manner and well indexed — an important point because the specialist will wish to refer to it frequently. Whenever he does so, he will be grateful for W i b o r g's meticulous approach and the comprehensive detail which it provides.

In due course, this report is to be enhanced by accounts of the phytoplankton at the coastal stations by Professor B r a a r u d and of the zooplankton at Station M by Mr. Ø s t v e d t.

K. M. R.

O. E. Sette *et al.* "Progress in Pacific oceanic fishery investigations 1950—53." U. S. Dept. Int., Fish & Wildlife Serv., Spec. Sci. Rep. Fish., 11o. 75 pp., 29 figs. Washington, D. C., 1954.

Anon. "Pacific oceanic fishery investigations. Progress report 1953." 21 pp. Honolulu, Hawaii, 1954.

The 1950—53 activities of the "Pacific Oceanic Fishery Investigations" are summarized largely in pictorial form. Four main items are involved in this immense programme.

Yellowfin tuna resources are charted on a long-term basis of numbers caught per 100 long-line hooks. The main concentration is given by the 4-fish density line, enclosing an elongated area in the equatorial zone directly south of Hawaii, in about 2° N., 145° —160° E. This stock consists of older and larger fish than those along mainland shores and its sources of recruitment are still uncertain. Fluctuations in number are not definitely seasonal.

An extensive oceanographic survey has led to a better understanding of productivity in the mid-Pacific equatorial area. As a result of this, a concept of equatorial circulation has been evolved, which has revealed the existence of a subsurface counter-current and an upwelling of dissolved nutrients (phosphate). The ensuing productivity chain is initiated by plankton growth and finally leads to an agglomeration of tuna, which shows some drift to the north.

Cannery acceptability of yellowfin over 150 lb. is limited by the darker colour of the flesh.

By the end of 1953 technical experiments were in progress to adapt the Japanese long-line gear to American use by further mechanization. Although the Japanese use salted fish or squid, the trials were switched over to frozen bait, which, on thawing overnight, is still firm enough to be hooked.

The hooks were distributed through different depths, ranging from 150 to 450 feet; the best practice on the whole seemed to be to get the line well into deep water.

Midday seems to be the most favourable time of the day. When the light penetrates deepest, the feeding seems to be heaviest, which suggests that the yellowfin finds the long-line bait mainly by sight.

Skipjack pole-and-line fishing forms the basis for the principal fishery of the Hawaiian Islands. The catch is limited by the range of the boats, and the scarcity of live bait, rather than the range of the skipjack. Under present working conditions winter catches are very low and this seasonal fluctuation prevents the development of a stable fishing industry. This demonstrates the need for information on distribution and movements of the Hawaiian skipjack stock.

Winter scouting for surface schools was extended over an area beyond the range of the fishermen. A hydrographic survey with the geomagnetic electrokinetograph revealed a complex system of currents with eddies downstream of the islands. These seem to bring up enriched waters and although biological conditions are not known in detail, it is believed that the summer as well as the winter current systems may enhance biological production.

Even apart from such local concentrations, skipjack larvae outnumber the yellowfin several times in mid-Pacific waters. This implies that the skipjack stock must be tremendous, so that the scarcity of live bait is considered to be the bottleneck for mid-Pacific pole-and-line fishing for skipjack.

It goes without saying that **live-bait substitutes** should replace those stimuli in live bait which evoke the tuna's attack. Since paying returns from pole-and-line fishing depend on the tuna being whipped up to a sort of frenzy of

activity, it seems possible that here a more complete set of stimulating factors is required than in long-lining. Moreover, different stages of attack might be related to different stimuli.

The reviewer wishes to stress the fact that the experience of common fishermen seems to have hit upon some notions regarding the tuna's susceptibility to different kinds of stimuli. The stimulus produced by a ruffled sea surface seems to raise the tuna's excitement and proneness to strike a hook (Anon. *Fisheries Newsletter,* Sydney, 1950, **9** (5) : 16). Accordingly, splashing the water is included in several Pacific native methods of angling for tuna. The Japanese have introduced sprinklers instead. Finally taste and smell seem to be of minor importance when the excited tunas strike feathered jigs.

In a pond at the University of Hawaii Marine Laboratory at Coconut Island experiments were made on tuna in order to find out whether they use taste, smell, sight, hearing, or combinations of these to locate food. Although some observations on conditioning of tunas and their acuity of vision are interesting from a biological point of view, the results of this part of the programme are not yet sufficient to meet the urgent needs of a promising fishery.

Extensive taste/smell experiments showed that tuna were most sensitive to extracts made from the tissues of fish; subsequent trials at sea were disappointing. No feeding reactions were evoked by any of 73 chemical compounds, including amino acids, vitamins, aromatics, and various nutritional biochemicals.

Another series of experiments dealt with the reactions of tuna to artificial light generated from an arc lamp, a projection lantern, and electric light bulbs (after dark, under constant illumination from two 60-watt bulbs). The fish were attracted to continuous white light of moderate intensity (about 70 to 450 foot-candles). Similar experiments were made with interrupted white light. Although this approach is somewhat beyond the scope of the live-bait problem, it would, in the reviewer's opinion, still be worth while to proceed along this line of research, since several fisheries depend on attraction by lights. However, in studies of the reactions of animals with image-forming eyes that can be compared to a photographic camera, it should be realized that it is the images projected on the retinas which are actually perceived. Local intensities of these images depend on the brightness of the light source, i.e., the quantity of light-energy given off by unit of emanating surface per unit of time. This physical property of the (lens-less) light source should therefore be duly taken into account.

Finally, tunas were exposed to sounds of various frequencies from a sound generator, for which they displayed only a faint interest, to say the most of it. This arrangement was contrary to the taste/smell experiments that had wisely been initiated with extracts made from fish tissues and thereafter passed over to simple compounds. When in search of innate reactions in wild (non-conditioned) tunas, primary trials should, in the reviewer's opinion, be related to the complex signals that announce food in nature. Initial attraction is likely to be brought about by far-reaching signals; one of these is sound. Malay fishermen are known to listen for the rushing sound of schools of small fish before shooting their nets (F i r t h, Geogr. Journ., London, 1943, **101**, I (5/6) : 193—205). Tunas should be exposed to a reproduction of such a rushing sound, rather than to uninteresting sounds from a generator that make no sense to any non-conditioned fish. Very low (even infrasonic) frequencies should be included in the primary experiments, since there are

reasons to suppose that in the disturbance caused by fins, a considerable part of the energy is distributed in these ranges.

In the section on sounds, no mention is made of the advantage of wooden ships for pole-and-line fishing over steel ones, which are noisier and apt to scare off the tunas.

Mobility is considered to be a desirable quality for a bait substitute, but difficult to provide. In the reviewer's opinion an electrically driven jerking jig might be worth trying. Papuans bite the fish used for bait in the head before casting; a few of these wounded fish seem to cause enough commotion to start the tunas attacking. Natives of the Society Islands are known to pinch the bait fish between thumb and finger for the same purpose (N o r d h o f f, Journ. Polynesian Soc., New Plymouth, N. Z., 1930, **39** (154) : 137—173).

Albacore investigations were initiated in 1953 with the exploration of potential fishing grounds north of Hawaii. The concomitant hydrographic survey of the area seems to reveal circulation features thought to be favourable to production and concentration of food for albacore. Results were still scanty by the end of 1953, but the complete picture will in time no doubt make a valuable guide in the development of a large-scale fishery.

The work of the team as a whole is backed by a bibliographic research, including translations of Japanese and other foreign publications.

J. Westenberg.

H. J. Aurich. "Verbreitung und Laichverhältnisse von Sardelle und Sardine in der südöstlichen Nordsee und ihre Veränderungen als Folge der Klimaänderung." Helgoländer Wiss. Meeresunters., **4**, 3, S. 175—204, Abb. 7. List (Sylt), 1953.

The paper deals with the occurrence of the anchovy (*Engraulis encrasicholus*) and the pilchard (*Clupea pilchardus*) in the North Sea, especially the south-eastern part. It is shown that great increases in the density of these species have taken place during recent years particularly. This is proved by records of occurrence and by estimates of the size of the spawning populations from period to period. The size of the spawning populations was determined from the number of eggs (and larvae) taken by the Hensen nets under a square metre of surface.

The patchy distribution of the anchovy in coastal waters of the southern North Sea and in the Zuider Zee — until this was artificially closed in 1932 — has long been well known. Some authors had expressed the opinion that the stocks there were more or less independent. A u r i c h, however, presents evidence from which he concludes that "invasions" from the Atlantic have taken place, as it is not possible to explain the increases through natural fluctuations. There have been three major invasions:— 1) just after 1930, 2) in 1940—42, and 3) in 1949—50. This applies especially to the waters off the east Friesian coasts. Before 1930 the number of eggs (the Zuider Zee not considered) did not exceed 2 per m^2., the spawning areas were small, and no eggs and hardly any larvae were found as far north as Helgoland. In 1930 and in the following years eggs and larvae were met with on 15 % of the stations in the German Bight at which the Hensen net was used, and a density of 24 per m^2. was recorded. At the same time, the spawning area became greatly extended both northwards and towards the more open parts of the North Sea. Eggs and larvae were found off the estuary of the Elbe, off Helgoland, and in the Lister Deep, and from 1938 they appeared in the Kattegat and in the western part of the Baltic. According to investigations

carried out in 1947 and later, an enormous brood was spawned in 1949. Eggs and larvae were found at 93 % of all stations, the maximum number of eggs being 3,885 per m^2. and of larvae 594, for the same unit. The average number of eggs on stations at which more than 100 were found amounted to 660 per m^2., or considerably more than the normal for cod, whiting, or sprat. The author arrives at the following general conclusions:—

1) The main spawning does not take place in the shallow coastal waters, as would be expected according to earlier findings, but occurs in the offshore water masses.
2) There are three more or less distinct spawning areas: off the Friesian coast, in the Helgoland—Hever region, and in Lister Deep.

   It is stated that these areas offer the most favourable temperature conditions, the lower temperature limit for the spawning being 13·0—13·5°C. Spawning takes place from the end of May to the end of July, culminating between mid-June and mid-July, when the temperature ranges between 15·0 and 20·0°C.
3) The salinity does not seem to have any limiting effect as it ranges from 17 to 33 ‰ between spawning places.
4) The spawning intensity decreases from south to north, the relative intensities in the three areas being as 6, 4, and 1.
5) Judged by the intensity of spawning the anchovy stock in the south-eastern North Sea was about 6,000 times larger in 1948—1952 than in 1902—1929.

In the case of the pilchard even more far-reaching changes have taken place. Before 1930 this fish did not seem to penetrate at all into the North Sea through the English Channel, though it might be observed on the east coast of Scotland, on the west and east coasts of southern Norway, and even in the Kattegat. From the records of Dutch, English, and German investigations as far back as 1891, there is no evidence of spawning in the southern North Sea until 1949. Since then, both eggs and larvae have been met with regularly. The spawning area is located in the Atlantic water coming through the English Channel and the minimum salinity required is 33 ‰. Spawning takes place from early May to late September at temperatures ranging from 7 to 18·5°C.; it culminates in June and July. The greatest numbers (per m^2.) of eggs and larvae found were 648 in July 1952 and 639 in June 1951. The highest averages for a whole month were 125 eggs (July 1951) and 117 larvae (June 1951).

The author emphasizes the point that the greatly increased stocks of these two species in the southern North Sea during recent years can only be explained by assuming a northward expansion of their distribution areas, in conjunction with an inflow of warm water from the Atlantic Ocean. In order to prove this, he draws attention to a number of other faunistic changes which have taken place at the same time in the area, and to similar well known changes from other northern waters. His documentation is highly convincing. The paper is a very valuable contribution to the literature dealing with increased temperatures in northern waters during the past 30 years or so and the consequent changes in marine animal life. *Arni Fridriksson.*

T. B. Bagenal. "The growth rate of the hake, *Merluccius merluccius* (L.), in the Clyde and other Scottish sea areas". Journ. Mar. Biol. Assoc. U. K., **33**, 1, pp. 69—95, 13 figs., 1 pl. Cambridge, 1954.

The observations recorded in this paper cover the period June 1949 to March 1953, during which a series of research-vessel trawlings were made at

irregular and sometimes lengthy intervals in restricted localities in the Clyde area to the west of Scotland, an area where hake are common but do not occur all the year round in quantity sufficient to maintain a regular fishery primarily for hake. Whenever hake were caught they were measured, but it was not until December 1952 and thereafter that otoliths were taken for age determination and the fish were sexed. In all, 2,250 hake were measured from the Clyde area, and the otoliths were taken from 585 of these.

The basis chosen for the determination of the growth-rate was the Petersen method of observing modal lengths. The data presented are arranged so as to show the mean lengths and length ranges, at each trawling, of six populations distinguished by the year in which they are presumed to have been spawned. It is to be regretted, in view of the apparently wide differences between the results shown and those of earlier workers, that more otoliths were not taken over a longer period. However, direct reading of the otoliths and back calculations corroborate very well the results from the length-frequency measurements.

The growth-rate determined for the Clyde area hake is very much faster than that determined for hake over wider eastern Atlantic areas by earlier workers. The annual length increments, as determined, are about 20, 15, and 11 cm. respectively in the second, third, and fourth years, the hake reaching an average length of 77 cm. by the age of 4½ years. These results are compared with those of Hickling, which indicated a mean annual length increment of 8·7 cm., being about 6 and 9·5 cm. in the third and fourth years, to reach an average length of 73 cm. in 9½ years — a growth-rate approximately only half as fast as that determined by Bagenal. Yet Hickling's results were based on a mass of observations and Bagenal does not doubt the validity of Hickling's age determination from otoliths. Doubtless Bagenal was somewhat surprised by his own findings, and he tries, without coming to any definite conclusions other than that the Clyde area growth-rate was indeed higher than that determined in other areas by other workers, to discover reasons for the differences. It is, although Bagenal does not mention the fact, in favour of his results being genuine and not caused by, for instance, sampling or age-determination errors, that his curve for hake growth-rate is of the shape to be reasonably expected, and as deduced theoretically by von Bertalanffy, whereas the almost straight line curve fitting Hickling's results is not. The capture in the Clyde area in October 1949 of hake of length 5—10 cm. was especially fortunate, and provides data about young fish which previously had been lacking.

It might then be concluded that the Clyde area hake have an unusually rapid growth-rate, or indeed that they are a separate stock from that exploited by the fisheries to the west of the British Isles, but such a simple conclusion is scarcely tenable in the light of additional evidence presented by Bagenal showing the growth-rate of hake caught off the west of Scotland by the "Explorer" to be approximately the same as that for the Clyde area; and Hickling could find little difference between hake growth-rates west of Scotland and south-west of Ireland.

Bagenal, in his discussion of results, dwells largely on differences between his findings and those of other workers, which, indeed, is the outstanding feature of the paper. In so doing he has apparently overlooked the similarity that if, from Hickling's data, the greatest length of fish in each age-group is plotted against age, then the resulting curve approximately continues that for his own Clyde area growth-rate into the higher age-groups which he did not sample; this indicates that the restricted Clyde area might perhaps be very much a "fringe area" as regards the main hake stock.

The paper is logically divided into sections and well provided with figures and tables, but the positioning of the figures and tables on the pages might have been improved upon so that the text was not so broken and scattered and thus rather awkward to read. In view of the fundamental importance, in any fish population considerations, of an accurate knowledge of the growth-rate of the fish, Bagenal's paper is worthy of special notice and is stimulating, not only to those persons who have to do with hake, but to all engaged in fish population studies. Variations in the growth-rate of hake, be they real or apparent, pose a problem worthy of urgent further attention.

A. R. M.

K. Bonham, F. B. Sanford, W. Clegg, and **G. C. Bucher.** "Biological and vitamin A studies of dogfish landed in the State of Washington (*Squalus suckleyi*)". State of Washington, Dept. Fish., Biol. Rep. 49 A, pp. 83—114, 41 figs. Seattle, 1949.

This paper describes in rather general terms the results of certain researches on the biology of the spiny dogfish (*Squalus suckleyi*) landed in the State of Washington and especially on the vitamin A content of their livers. In this State the dogfish are, in fact, caught mainly for the purpose of obtaining vitamin A from the livers, the carcasses being mostly discarded at sea as worthless. This dogfish-liver industry is of very recent origin, the landings in 1937 being only 17,000 lb., but by 1943 this figure had grown to nearly $2^{3}/_{4}$ million pounds.

In their investigation the authors found that the vitamin A content of the livers showed important variations depending upon sex, maturity, liver colour, season, and fish size. The most important of those factors was size, large fish as compared with small fish of the same sex having a greater ratio of liver weight to body weight, darker livers, more oil per liver, liver and liver oil of higher potency, and more vitamin A per liver. With increasing size, the greatest increase in vitamin A occurred after the onset of sexual maturity. Consequently, mature fish are on the average of much greater commercial value, weight for weight, than the smaller, sexually immature fish.

In connexion with the general biology of these fish tagging experiments were carried out. By the end of December 1943, 4,404 fish had been tagged. By August 1944 recoveries amounted to 6 % of the releases, some tagged fish being recovered from as far south as northern California and as far north as the vicinity of Vancouver. There is some indication of a seasonal migration northward in spring and summer and southward in fall and winter, but the evidence is not clear-cut and further investigation is needed.

Brief notes are also provided on length frequencies, reproduction, growth-rates, food, and age determination.

G. A. S.

R. M. Laws. "The Elephant Seal (*Mirounga leonina* Linn.) 1. Growth and Age". Falkland Islands Dependencies Surv., Sci. Rep. 8, 62 pp., 28 figs., 5 pl. London, 1953.

It has been a pleasure to read this, the first of a series of papers on the biology of the antarctic elephant seal. A worthy precursor, however, was the author's paper in the same series (No. 2, 1953), in which he described a new and very promising method of age determination in seals, based on the study of the concentric zones visible in cross-sections of the canine teeth.

The author collected his material during prolonged sojourns in the Antarctic; he was at Signy Island, South Orkney Islands, from February 1948 to February 1950, in the Falkland Islands in February—March 1951, and in South Georgia from March to December 1951.

After a short, but adequate, introduction dealing with nomenclature and previous investigations, the author describes his collecting methods. Working shorthanded, he had to overcome many formidable difficulties in the course of making all the external measurements and weighings and of collecting the material for anatomical and histological studies. Two hundred and twenty-six elephant seals were killed to furnish material for full investigation.

A description is given of external characters, anatomy, and dentition. An interesting point is the length measurements of the intestines, given for 89 specimens, by itself a very impressive piece of work, since the small intestine is usually 20 to 25 times the body-length. In one case, in a male of 189 inches, the intestine was 662 feet, 42 times the body-length. The author suggests that this unusual length of the intestine is in some way related to the food (cephalopods).

In the following section on growth and age, the author discusses possible methods of age grouping, the development of the pup, and the growth of the male and female after weaning. Tables and diagrams, including some very good sketches and drawings made by the author, greatly enhance the value of this chapter. The determination of the age of 226 specimens has enabled the author to draw a complete growth-curve for the animals up to 12 years of age. The female attains sexual maturity at an age of 2 years and a length of about 96 inches. From that point the growth-rate of the female is lower. Males have a very high growth-rate until sexual maturity is reached at an age of 4 years and a length of about 170 inches. The largest female and male killed were 138 and 217 inches respectively, but they can grow a little longer.

The author assumes that the rate of mortality is very high in the first year of life, perhaps as much as 50 %, this applying mainly to pups at sea, while among pups ashore the death-rate is usually low. From a census of dead and live pups in South Georgia in 1951 the author estimates a death-rate ashore of about 3 % from birth to weaning. To anyone with a cursory knowledge of rookeries in South Georgia it seems surprising that the normal death-rate is not higher, but under certain circumstances, also described by the author, the death-rate of pups can evidently be very high. Among adults, deaths from natural causes are presumably few.

From a study of the age composition of commercial catches in South Georgia, where only large bulls are killed, and the age composition of his own material, the author concludes that the average of harem bulls in an unexploited stock is about 10 or 12 years, while the maximum age seems to be about 20 years.

In females the oldest individual found was 17 years old and the average expectation of life for a mature female may be about 10 years.

The reproductive cycle of the elephant seal and the result of the censuses carried out at Signy Island and South Georgia will be discussed in a later paper, and in that connexion probable mortality rates will be discussed further. We look forward to the next paper.

Johan T. Ruud.

T. A. Stuart. "Spawning migration, reproduction and young stages of loch trout (*Salmo trutta* L.)". Scottish Home Dept., Freshwater & Salmon Fish. Res., 5, 39 pp., 11 figs. Edinburgh, 1953.

Si nous avons acquis bon nombre de connaissances sur la reproduction artificielle de la truite commune (*Salmo fario*) et sur le développement ultérieur en pisciculture de ses œufs et de ses alevins, force nous est de reconnaître que, par ailleurs, nos connaissances sur les conditions de sa reproduction naturelle en rivière, et sur ses conséquences, sont malheureusement encore très insuffisantes. L'étude de T. A. Stuart sur le bassin de la rivière écossaise Tummel vient heureusement combler une importante partie de cette lacune.

Pour éviter toute confusion sur ce terme "loch trout" précisons tout d'abord que les populations étudiées sont celles de trois "lacs de barrage" partiellement ou totalement artificiels, de 4, 15, et 120 hectares, à niveau variable, et tous alimentés par un ou plusieurs tributaires. Les truites qui les peuplent y atteignent un poids de 170 à 450 g. et doivent donc être considérées comme des truites communes de rivière vivant en lac de barrage et non comme des "truites de lac" telles que celles du Léman.

L'auteur met en évidence le fait que, lorsqu'elle a lieu, la maturation sexuelle des truites se produit chaque année à la même période quelque soient les conditions climatiques. Le principal facteur provoquant la migration ascendante du lac dans ses tributaires semble être l'abaissement de la température de l'eau du lac et des tributaires. Ce sont les truites de grande taille qui apparaissent les premières sur les frayères, au début du frai ce sont les femelles qui sont nettement prédominantes, à la fin ce sont les mâles. 50 % des reproducteurs ne pondent qu'une année sur deux. En pays froid l'été constitue une période de récupération et de croissance fort courte entre deux hivers; *a fortiori* si les deux hivers sont tous deux consacrés à une reproduction qui représente une période de consommation intense. La ponte bisannuelle d'une partie du stock constitue alors une défense contre une possible dégénérescence.

Les observations sur l'établissement de la frayère confirment en tous points les études antérieurs de Hobbs et de Curtiss. Stuart apporte en outre une précision importante sur sa localisation. L'emplacement choisi de préférence, en queue d'un "pool", juste avant le début du "courant" qui lui fait suite, correspond aux caractéristiques ci-après, assurant la meilleure survie de la ponte:—

1°) risque minimum d'envasement ou d'ensablement des œufs lors des crues;
2°) existence d'un courant pénétrant obliquement de haut en bas dans les graviers et assurant aux poches d'œufs le renouvellement d'eau qui leur est nécessaire. Placés à cet endroit, sur la surface des graviers, des cristaux de permanganate de potasse disparaissent presque aussitôt sans trainée violette dans le courant à l'aval, le courant pénétrant obliquement dans les graviers entraînant la coloration avec lui. Pour les repeuplement par œufs, cette vérification très simple pourra permettre de répérer au préalable les emplacements les plus favorables.

L'étude de la vie embryonnaire et larvaire, tant en rivière qu'en laboratoire, nous apporte des notions de toute première importance sur les possibilités de défense de l'œuf et de l'alevin tant contre l'envasement et l'ensablement que contre les invertébrés prédateurs. Les œufs sont très sensibles à l'envasement et à l'ensablement mais, étant enfoncés profondément, n'ont guère à redouter les invertébrés predateurs qui se localisent seulement dans la couche superficielle des graviers (5 cm.). Une fois éclos, les alevins vésiculés ont des possibilités de défense insoupçonnées jusqu'alors contre un envasement ou un ensablement qui ne se prolonge pas trop; le léger courant qu'ils provoquent par leurs

nageoires pectorales puis par leur queue, éloigne d'eux les sédiments. Ils "crachent", enrobés de mucus qui l'agglutine, le trop plein de vase qu'ils avalent. Enfin ils se dispersent sous les graviers, et ne traversent, rapidement d'ailleurs, la couche supérieure dangereuse (présence d'invertébrés prédateurs) pour émerger en eau libre, qu'une fois leur vésicule résorbée.

Les observations faites passé ce stade ont montré que l'action protectrice du gravier n'était pas finie avec la sortie des alevins devenus jeunes poissons. Pendant un certain temps ceux-ci sont encore capables, à la moindre alerte, de plonger dans les graviers jusqu'à 30 cm. de profondeur en quelques secondes. Ce détail permet de penser qu'en fait les alevins sont mieux armés contre les prédateurs qu'on ne l'avait cru jusqu'à présent.

Débordant le cadre expérimental, S t u a r t montre que les boîtes d'alevinage en matière plastique, qui lui ont servi à suivre l'évolution des œufs dans les graviers, peuvent être employées avec avantage et économie pour le repeuplement par enfouissement d'œufs dans les graviers. Il en donne les conditions de réussite.

Sur le plan pratique des repeuplements par œufs, à l'aide de boîtes d'alevinage en matière plastique, ce travail de S t u a r t a le grand intérêt de confirmer en tous points les études que nous avons poursuivies en France depuis 1947. Il confirme les résultats obtenus dans une douzaines de pays avec les boîtes d'alevinage en matière plastique moulées que nous avons mis au point en 1949.

Sur le plan scientifique, ces travaux, poursuivis de 1949 à 1953 au laboratoire de Pitlochry, ont le mérite d'apporter une contribution de tout premier ordre à la connaissance des conditions de reproduction naturelle de la truite et de la survie de sa progéniture.

R. Vibert.

G. I. Murphy, and **K. C. Elliott.** "Variability of longline catches of Yellowfin Tuna". U. S. Dept. Int., Fish and Wildlife Serv., Spec. Sci. Rep. Fish, 119, pp. 1—30, 6 figs. Washington, 1954.

In any detailed investigation of fishery problems in which use is made of catch data, a knowledge of the magnitude of the random sampling error in the catches is essential. Such information is necessary, for example, when estimates of population abundance are required (i.e., in problems involving interval estimation), or in comparing catches taken at different times or in different localities (i.e., in tests of significance). The magnitude of these random sampling errors depends on, among other things, the size of sample and the spatial distribution of the fish.

Information on the variability of trawl catches is now being steadily accumulated but, up to the present time, few data appear to be available on the magnitude of the sampling error in catches by lines. The present paper sets out to fill part of this gap in our knowledge by providing estimates of the variability in longline catches of yellowfin tuna in the western equatorial Pacific.

The data used in this study are taken from two sources, namely, (1) statistics of the Japanese commercial fishery, and (2) more detailed records of catches made by research vessels of the U. S. Fish and Wildlife Service. The two types of gear differed in respect of length of line and, consequently, in number of hooks; the commercial vessels used about 2,000 hooks while the research vessels used 240—480 hooks.

The first part of the paper is devoted to an examination of the spatial distribution of the tuna. This is approached in three ways, (a) by a study

of the catch of individual hooks along the line, (b) by a comparison of the variability of catches of tuna and black marlin, and (c) by an investigation of the relationship between the mean and the variance of sets of commercial catches. The authors conclude that there is evidence to support the hypothesis that the yellowfin tuna is a schooling species and that catches follow a contagious distribution.

The second part of the paper deals with the estimation of the sampling error of longline catches and the relationship between the magnitude of the error and the number of hooks employed. An estimate of the sampling error is most easily obtained when sets of replicate hauls are available. The data at the authors' disposal were not amenable to this type of analysis without modification, as commercial catches were not recorded individually and the research-vessel catches consisted of single shots from widely separated areas. To overcome this, the individual catches of the research vessels were divided into subsets and analyses of variance were made on data from a number of stations using subsets as replicates.

An essential requirement for the analysis of variance to be valid is that the sampling error be independent of the mean level of the observations. This was found not to hold for the yellowfin catches, for which the variance increased with the mean, and the data had to be transformed prior to analysis. Two transformations were tried, the inverse sinh transformation and the logarithmic transformation. Both appeared equally successful, and the simpler logarithmic transformation was employed. The analyses of variance pointed to an inverse relationship between the variance of the transformed catches and the number of baskets in the gear. Extrapolation of this result indicated that the variance of commercial catches was considerably higher than the relationship suggested.

The original data on which all analyses are based are included.

The paper does demand some knowledge of statistical methods on the part of the reader.

J. A. P.

M. B. Schaefer. "Some aspects of the dynamics of populations important to the management of commercial marine fisheries". Bull. Inter-American Tropical Tuna Comm., **1**, 2, pp. 27—56, 10 figs. La Jolla, California, 1954.

The study of the dynamics of exploited fish populations forms probably the most important single subject of fishery research today. In Atlantic fisheries the approach to this study has recently been the analytic one, introduced by Baranov in 1918, and developed more fully, for example, by Beverton and Holt. This approach involves the study of many detailed characteristics of the fish population — the growth-rate of the individual, the mortalities due to fishing and other causes, etc. There is therefore a need for very detailed information about the fish population. In the present paper the fish population is treated as a single unit in its ecological environment. The increase of the population is then assumed to be determined, for constant environmental factors, by a function f(P) of the size of population, this function being continuous, positive, and single valued. It is zero both when the population is zero, and at its maximum. In the calculation the logistic function $f(P) = k_1L(L—P)$, where L is the maximum population, has been used. The toll of the fishery is assumed to be proportional to the fish population, P, and the intensity of fishing, F, or, in other words, is equal to k_2PF. The actual change in the population is then the difference between its natural rate of increase

and the toll of the fishery; the population is steady when the two are equal. Hence the greatest yield from an equilibrium population is achieved when the natural rate of increase is at a maximum, i.e., when $P = 1/2\ L$. This is of course mainly a restatement of Graham's sigmoid curve, in more elegant mathematical terms.

To apply this to a fishery in order to determine f(P) and hence the population level for maximum equilibrium yield, it is, in theory, only necessary to plot natural rate of increase, that is, catch plus population change, against population. This may be contrasted with the large amount of information needed for the analytical method.

In practice the information needed is rather more than merely statistics of catch and effort; to combine the catch, known in weight, with the change in population, known usually in catch per unit effort, in order to get the natural rate of increase, some knowledge of the rate of fishing is needed, though not so exactly as is needed in the analytical approach.

Schaefer applies the theory to the Pacific halibut and the Californian sardine fisheries. The general form of the points of the natural rate of increase f(P), when plotted against population P, is, for both fisheries, of f(P) increasing with P, but flattening off at the higher observed values of P, although the scatter is considerable. The fitted curve for a logistic population is then a parabola, with its maximum rather to the right of the observed points. This is interpreted as meaning that f(P), i.e., the equilibrium catch, has a maximum at a greater value of P, and hence at a lower rate of fishing, than that at present experienced; that is, the stock is "overfished". It is worth noting that if the stock is undergoing long fluctuations, over several years, then high catches and hence high values of f(P) will be associated with high population values, and may thus give rise to the observed distribution of points. It is likely that this occurs to some extent in many fisheries and would tend to distort the curve, pushing the maximum to the right.

A more fundamental criticism of the method is that the natural rate of increase is not a single-valued function of population, that is, a fish population cannot be treated as a single mass of protoplasm, but its structure — its age composition, etc., — must be taken into account. For instance, young fish grow much faster, weight for weight, than old fish, though having probably the same losses due to natural mortality. A heavily fished stock consists mostly of young fish, and hence can increase very rapidly when the fishing is removed; conversely, a virgin stock of old fish is at first reduced very rapidly by the imposition of heavy fishing. Furthermore, one of the important factors in the population change, the recruitment, will be determined, not by the present population, but by that several years before — four or five years in the case of North Sea plaice, and more in the case of Pacific halibut.

Compared with the simple analytic approach in which growth, mortality, etc. are assumed constant, this method gives a more realistic picture of the extreme population values, particularly when the population is near its maximum, that is, at very low fishing intensities. On the other hand, the method used in this paper is not able to make such detailed and accurate predictions of the effect of small changes in fishing rate, or age at first capture.

Schaefer has also introduced the dynamics of the fishing fleet itself as the second element of a predator-prey system. The rate of change of the size of the fleet is taken to be proportional to the difference between the population abundance and the level at which catches will just balance costs. This is a more precise formulation of Graham's statement that a fishery will go on expanding until there is no profit. Following the mathematical

theories of Lotka and Volterra, Schaefer shows that under these conditions the fishery will reach a position of stable equilibrium at the point where costs and returns are equal. This point may be at a population level well below that giving the maximum equilibrium catch.

The theory is also used to describe the growth of a fishery from an unexploited condition. If the increase in fishing is rapid enough, then the yield may for a short time be not only above the yield at the stable "overfished" condition, but also above the greatest possible equilibrium catch. This implies that the fact that the present yield is less than the yield obtained for a short time in the early stages of a fishery is not by itself proof that the yield could be increased by some regulation.

The methods described in this paper, though they cannot provide such precise or confident answers as the fully developed analytical approach, do, however, enable statements to be made concerning the status of a fishery when adequate statistics of catch and effort are available over a reasonably wide range of fishing effort and population size, particularly from the early stages of the fishery. These answers are, however, not beyond doubt, due to long-term fluctuations, etc., and the method does not provide a full alternative to the detailed analytical approach.

J. A. G.

Current Bibliography.

Prepared by the Editor with the Assistance of Mr. A. R. Margetts.

NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list will receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

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